PB84-167683

Benzene Emissions from Benzene Storage Tanks Background Information for Proposal to Withdraw Proposed Standards

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Mar 84

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-84-004
March 1984

Air

PB84-167683

EPA

Benzene Emissions From Benzene Storage Tanks — Background Information for Proposal to Withdraw Proposed Standards

NESHAP

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-450/3-84-004		PB84 167683

4. TITLE AND SUBTITLE	5. REPORT DATE
Benzene Storage Tanks - Background Information for Proposal to Withdraw Proposed Standards	March 1984
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning and Standards Environmental Protection Agency Research Triangle Park, North Carolina 27711	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. 68-02-3063
12. SPONSORING AGENCY NAME AND ADDRESS DAA for Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711	13. TYPE OF REPORT AND PERIOD COVERED Draft
	14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

It is proposed to withdraw the proposed National Emission Standards for Hazardous Air Pollutants for the control of Benzene emissions from Benzene Storage Tanks. Previously, standards had been proposed under Section 112 of the Clean Air Act. This document contains background information considered in the proposed withdrawal of those previously proposed standards.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution Pollution control Storage tanks Floating roof and seal systems Chemical manufacturing plants Benzene National Emissions Standards for Hazardous Air Pollutants	Air Pollution Control	13 B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Unlimited	Unclassified	109
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-450/3-84-004

Benzene Emissions from Benzene Storage Tanks — Background Information for Proposal to Withdraw Proposed Standards

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning Standards
Research Triangle Park, North Carolina 27711
March 1984

This report has been reviewed by the Emission Standards and Engineering Division of the Office of Air Quality Planning and Standards, EPA, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use. Copies of this report are available through the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711, or, for a fee, from the National Technical Information Services, 5285 Port Royal Road, Springfield, Virginia 22161.

ENVIRONMENTAL PROTECTION AGENCY

Background Information
Benzene Storage Tanks

Prepared by:

Jack R. Farmer 3/1/84
Date

Jack R. Farmer
Director, Emission Standards and Engineering Division
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

1. The Federal Register notice proposes withdrawal of proposed national emission standards (45 FR 83952; December 19, 1980) for benzene emissions from all existing and new Benzene Storage Tanks.

2. Copies of this document have been sent to the following Federal Departments; Labor, Health and Human Services, Defense, Transportation, Agriculture, Commerce, Interior, and Energy; the National Science Foundation; the Council on Environmental Quality; members of the State and Territorial Air Pollution Program Administrators; the Association of Local Air Pollution Control Officials; EPA Regional Administrators; and other interested parties.

3. The comment period for review of this document is 30 days. Mr. Gilbert H. Wood may be contacted regarding the date of the comment period.

4. For additional information contact:

   Gilbert H. Wood
   Standards Development Branch (MD-13)
   U.S. Environmental Protection Agency
   Research Triangle Park, NC 27711

5. Copies of this document may be obtained from:

   U.S. EPA Library (MD-35)
   Research Triangle Park, NC 27711

   National Technical Information Service
   5285 Port Royal Road
   Springfield, VA 22161

TABLE OF CONTENTS

Section		Page
	LIST OF FIGURES	v
	LIST OF TABLES	vi
1	SUMMARY	1-1
	1.1 Summary of Changes Since Proposal	1-1
	1.2 Summary of Proposal to Withdraw the Proposed Standards	1-1
2	SUMMARY OF PUBLIC COMMENTS	2-1
	2.1 Selection of Benzene Storage Tanks for Regulation	2-1
	2.2 Health and Environmental Impacts	2-14
APPENDICES		
A	EMISSIONS SOURCE TEST DATA AND ANALYSIS	A-1
B	METHODOLOGY FOR ESTIMATING LEUKEMIA INCIDENCE AND MAXIMUM LIFETIME RISK FROM EXPOSURE TO BENZENE STORAGE TANKS	B-1

LIST OF FIGURES

Figure		Page
A-1	Process and instrumentation schematic	A-3
A-2	Plan view of noncontact bolted IFR	A-5
A-3	Elevation view of noncontact bolted IFR in test tank . .	A-6
A-4	Plan view of contact welded IFR	A-7
A-5	Elevation view of contact welded IFR in test tank	A-8
A-6	Plan view of contact bolted IFR	A-9
A-7	Elevation view of contact bolted IFR in test tank	A-10
A-8	Example of fitting emission bench test apparatus	A-19

LIST OF TABLES

Table		Page
1-1	Changes in Nationwide Impacts	1-2
2-1	List of Commenters on the Proposed National Emissions Standards for Hazardous Air Pollutants for Benzene Storage Vessels	2-2
2-2	Vessels Containing Mixtures That May be More Than 10 Percent Benzene	2-13
2-3	Comparison of Emissions as Calculated from the EPA Series and the 2519/2517 Series.	2-20
2-4	Internal Floating Roof Tank Emissions by Source.	2-22
2-5	Emissions from a Typical Benzene Storage Vessel.	2-23
2-6	Comparison of Convective and Permeability Losses from Internal Floating Roof Seal Systems in the Model Tank.	2-28
2-7	Model Tank Emissions (Mg/yr) from a Fixed Roof Tank and a Typical Internal Floating Roof Tank	2-29
2-8	Emissions from New and Existing Model Plants	2-30
2-9	Nationwide Emissions from New and Existing Benzene Storage Tanks.	2-31
A-1	Summary of Test Conditions for Phase 1 and 1R	A-11
A-2	Summary of Test Conditions for Phase 2 and 2R	A-13
A-3	Summary of Test Conditions for Phase 3 and 3R	A-15
A-4	Summary of Test Results for All Potentially Relevant Tests	A-16
A-5	Summary of IFR Deck Fitting Emission Tests	A-20
A-6	Permeability of Polyurethane Coated Nylon Fabric	A-21
A-7	Comparison of Wiper Seals to Foam-Filled Vapor-Mounted Seals	A-23
A-8	Comparison of Liquid-Mounted Seal to Vapor-Mounted Seal	A-24
A-9	Bolted Deck Seam Emissions	A-26
A-10	Comparison of Emissions as a Function of Liquid Type	A-27

(continued)

LIST OF TABLES (Concluded)

Table		Page
B-1	Plants and Locations for Benzene Storage Tanks	B-4
B-2	Model Inputs for Each Type of Model Plant	B-10
B-3	Estimated Maximum Concentration and Exposure for Benzene Storage Tanks	B-16
B-4	Estimated Nationwide Health Impacts for Benzene Storage Tanks	B-21

1. SUMMARY

On December 19, 1980, the U.S. Environmental Protection Agency (EPA) proposed National Emissions Standards for Hazardous Air Pollutants (NESHAP) for benzene storage vessels under the authority of Section 112 of the Clean Air Act. The proposed standards were published in the Federal Register (45 FR 83952) with a request for public comment. A public hearing was held on June 9, 1981. Six individuals representing three organizations made presentations. A total of 22 comments from industry, two trade associations, and an environmental group were submitted during the comment period. Comments submitted relevant to the withdrawal decision and EPA's responses are summarized in this document. The summary of comments and responses serves as the basis for the proposal to withdraw the proposed standards.

1.1 SUMMARY OF CHANGES SINCE PROPOSAL

Since the standards for benzene emissions from benzene storage vessels were proposed (December 19, 1980; 45 FR 83952), estimated benzene emissions from this source category have declined considerably. This estimated reduction is due to revised emission factors based on new test data acquired since proposal. The basis for the revised emission factors is discussed in more detail in Section 2.2.2.1 of this document. Table 1-1 compares the estimated nationwide baseline benzene emission and health impacts due to benzene storage vessels at proposal with current estimated impacts.

1.2 SUMMARY OF PROPOSAL TO WITHDRAW THE PROPOSED STANDARDS

The Administrator is proposing to withdraw the proposal of the benzene standards for benzene storage vessels. This decision is based on several factors, including the broad amount of control currently

Table 1-1. CHANGES IN NATIONWIDE IMPACTS

Impact	At proposal	Current
Benzene emissions (Mg/yr)	2,200	620
Leukemia incidence (cases/yr)	0.12 to 0.82	0.043
Maximum lifetime risk	1.5×10^{-4} to 1.0×10^{-3}	3.6×10^{-5}

within the source category, the relatively small amount of emissions, the small estimated leukemia incidence and maximum lifetime risk at current control levels, and the inability to reduce health risks significantly with additional controls. This decision is discussed in greater detail in Section 2.1.2.

2. SUMMARY OF PUBLIC COMMENTS

A list of commenters, their affiliations, and the EPA docket entry number assigned to each comment are shown in Table 2-1. Twenty-two letters commenting on the proposed standards and the Background Information Document (BID) for the proposed standards were received. Because the proposed standards are being proposed for withdrawal, only comments and responses relevant to that decision are addressed in this document. Significant comments have been combined into the following two categories:

2.1 Selection of Benzene Storage Tanks for Regulation

2.2 Health and Environmental Impacts

2.1 SELECTION OF BENZENE STORAGE TANKS FOR REGULATION

2.1.1 Selection of Source Category

Several commenters contended that the proposed benzene storage emissions standard is not needed and, therefore, should be withdrawn. These comments address the following: (1) significance and relative proportion of risk associated with benzene storage emissions; (2) duplication of federal and State regulations and guidelines; (3) information indicating that risks are smaller than estimated in the preamble to the proposed standards; (4) acceptable residual risk; and (5) lack of data to demonstrate risk.

Comment: Three commenters stated that the EPA has not demonstrated that benzene storage emissions, relative to other benzene source categories, pose a significant risk that merits the adoption of a benzene storage standard (IV-D-10a, IV-D-16, IV-F-1). One of these commenters (IV-D-10a) stated that Section 112 requires that a NESHAP be established at the level that in the Administrator's judgement provides "an ample margin of safety to protect the public health from such hazardous air pollutant." According to the commenter the Supreme Court has held that, absent a "clear mandate" from Congress to eliminate all risk, the statutory

Table 2-1. LIST OF COMMENTERS ON THE PROPOSED NATIONAL EMISSIONS STANDARDS FOR HAZARDOUS AIR POLLUTANTS FOR BENZENE STORAGE VESSELS

Docket entry number[a]	Commenter/affiliation
IV-D-1	Edward W. Warren Kirkland and Ellis 1776 K Street, Northwest Washington, D.C. 20006 Counsel for the American Petroleum Institute
IV-D-2	R. W. Bogan GATX Terminals Corporation 120 South Riverside Plaza Chicago, Illinois 60606
IV-D-3	Edward W. Warren Kirkland and Ellis 1776 K Street, Northwest Washington, D.C. 20006 Counsel for the American Petroleum Institute
IV-D-4	John T. Barr Air Products and Chemicals, Inc. Box 538 Allentown, Pennsylvania 18105
IV-D-5	John Heinz Unites States Senate Committee on Energy and Natural Resources Washington, D.C. 20510 With attachment from Sun Petroleum Production Company
IV-D-6	J. C. Pullen Celanese Fibers Company Box 32414 Charlotte, North Carolina 28232
IV-D-7	Herman A. Fritscher Cities Service Company Box 300 Tulsa, Oklahoma 74102

(continued)

Table 2-1. Continued

Docket entry number[a]	Commenter/affiliation
IV-D-8	E. M. Vancura Union Oil Company of California Box 7600 Los Angeles, California 90051
IV-D-9	D. P. Martin Gulf Oil Company Post Office Box 2001 Houston, Texas 77001
IV-D-10	Geraldine V. Cox Chemical Manufacturers Association 2501 M Street, Northwest Washington, D.C. 20037
IV-D-10a	Lance S. Granger Chemical Manufacturers Association 2501 M Street, Northwest Washington, D.C. 20037 Attachment to docket entry IV-D-10
IV-D-11	Paul J. Sienknecht The Dow Chemical Company Midland, Michigan 48640
IV-D-12	Alfred G. Hoerrner Merck Chemical Manufacturing Division Post Office Box 2000 Rahway, New Jersey 07065
IV-D-13	Richard K. Meyers Texaco, Incorporated Post Office Box 509 Beacon, New York 12308
IV-D-14	F. M. Parker Chevron U.S.A., Incorporated 575 Market Street San Francisco, California 94105
IV-D-15	R. J. Samelson PPG Industries, Incorporated One Gateway Center Pittsburgh, Pennsylvania 15222

(continued)

Table 2-1. Concluded

Docket entry number[a]	Commenter/affiliation
IV-D-16	Daniel B. Rathbun American Petroleum Institute 2101 L Street, Northwest Washington, D.C. 20037
IV-D-17	John J. Moon Phillips Petroleum Company Bartlesville, Oklahoma 74004
IV-D-18	Dennis L. Gehlhausen Eli Lilly and Company 307 East McCarty Street Indianapolis, Indiana 46285
IV-D-19	David D. Doniger Natural Resources Defense Council, Incorporated 1725 I Street, Northwest Suite 600 Washington, D.C. 20006
IV-D-20	Wells Eddleman General Energy Consulting Route 1, Box 183 Durham, North Carolina 27705
IV-D-21	C. D. Mallach Monsanto Company 800 North Lindbergh Boulevard St. Louis, Missouri 63166
IV-H-1	T. L. Hurst Kerr-McGee Corporation Kerr-McGee Center Oklahoma City, Oklahoma 73125
IV-F-1	National Air Pollution Control Techniques Advisory Committee Transcript of Meeting for National Emission Standards for Hazardous Air Pollutants from Benzene Storage Vessels U.S. Environmental Protection Agency Office of Administration Research Triangle Park, NC 27711

[a]These designations represent docket entry numbers for Docket No. A-80-14. These documents are available for public inspection at: U.S. Environmental Protection Agency, Central Docket Section, West Tower Lobby, Gallery 1, Waterside Mall, 401 M Street, Washington, D.C. 20460.

term "safe" (regarding exposure levels), rather than meaning "absolutely risk-free," means a level that protects against a "significant risk of harm." The commenter noted that risk levels that the EPA has calculated are not "significant" as that term has been used by the court.

Two commenters (IV-D-16, IV-D-21) felt that the risk from exposure to benzene emissions is insignificant compared to other commonly accepted societal risks. Two commenters (IV-D-13, IV-D-16) noted that the risk from benzene storage emissions is insignificant in comparison to the background leukemia incidence risk.

Two commenters (IV-D-4, IV-D-13) further compared the risk from benzene storage emissions to other government determinations of risk acceptability and noted that, under these determinations, the risk from exposure to benzene storage emission sources would have been considered not worthy of regulation.

Response: The commenters are judging the significance of benzene storage vessels based on quantitative risk estimates. In general, quantitative risk estimates at ambient concentrations involve an analysis of the effects of a substance in high-dose epidemiological or animal studies, and extrapolation of these high-dose results to relevant human exposure routes at low doses. In the case of benzene, the effects observed were the result of high-dose epidemiological studies. The mathematical models used for such extrapolations are based on observed dose-response relationships for carcinogens and assumptions about such relationships as the dose approaches very low levels or zero. Quantitative risks to public health from emissions of an airborne carcinogen may be estimated by combining the dose-response relationship obtained from this carcinogenicity strength determination with an analysis of the extent of population exposure to a substance through ambient air.

Most exposure analyses are based on air quality models, available estimates of emissions from sources of a substance, and approximations of population distributions near these sources. EPA considers this the best practicable approach. Even though ambient monitoring data might be used to estimate quantitative risks to public health, these data are available only for a few locations near these sources. Thus, use of ambient monitoring data is not practicable. However, EPA has data to confirm that the public is exposed to benzene. For example, concentrations

up to 51 micrograms per cubic meter (on a 24-hour average) were found around a petrochemical plant in Philadelphia, Pennsylvania.

The air quality models used in exposure analyses generally estimate exposures out to 20 kilometers from the source. During exposure analyses, population and growth statistics are examined in conjunction with ambient concentrations. Using these factors and existing carcinogenicity strength determinations, estimates are then made of the degree of risk to individuals and the range of increased cancer incidence expected from ambient air exposures associated with a substance at various possible emission levels.

The assumptions and procedures discussed above for extrapolation and for exposure estimates for benzene emissions are subject to considerable uncertainty. A small portion of that uncertainty has been considered by calculating ranges at proposal. The ranges presented at proposal represent uncertainty in estimates of benzene concentrations to which workers were exposed in occupational studies of Infante, Aksoy, and Ott that serves as the basis for developing the benzene unit risk factor (Part I Docket Item II-A-31). The ranges presented represent 95 percent confidence limits on two sources of uncertainty in the benzene risk estimates. One source derives from the variations in dose/response among the three occupational studies upon which the benzene unit risk factor is based. A second source involves the uncertainties in the estimates of ambient exposure. In the former case, the confidence limits are based on the assumption that the slopes of the dose/response relationships are unbiased estimates of the true slope and that the estimates are log normally distributed. In the latter case, the limits are based on the assumption that actual exposure levels may vary by a factor of two from the estimates obtained by dispersion modeling (assuming that the source specific data are correct).

Other uncertainties associated with estimating health impacts were not quantified at proposal. EPA has extrapolated the leukemia risks identified for occupationally exposed populations (generally healthy, white males) to the general population for whom susceptibility to a carcinogenic insult could differ. The presence of more or less susceptible subgroups within the general population would result in an occupationally derived risk factor that may underestimate or overestimate actual risks.

To the extent that there are more susceptible subgroups within the general population, the maximum individual lifetime risks may be underestimated.

On the other hand, general population exposures to benzene are much lower than those experienced by the exposed workers in the occupational studies, often by several orders of magnitude. In relating the occupational experience to the general population, EPA has applied a linear, non-threshold model that assumes that the leukemia response is linearly related to benzene dose, even at very low levels of exposure. There are biological data supporting this approach, particularly for carcinogens. However, there are also data which suggest that, for some toxic chemicals, dose/response curves are not linear, with response decreasing faster than dose at low levels of exposure. At such levels, the non-linear models tend to produce smaller risk factors than the linear model. The data for benzene do not conclusively support either hypothesis. EPA has elected to use the linear model for benzene because this model is generally considered to be conservative compared to the non-linear alternatives. This choice may result in an overestimate of the actual leukemia risks.

EPA estimates ambient benzene concentrations in the vicinity of emitting sources through the use of atmospheric dispersion models. EPA believes that its ambient dispersion modeling provides a reasonable estimate of the maximum ambient levels of benzene to which the public could be exposed. The models accept emissions estimates, plant parameters, and meteorology as inputs and predict ambient concentrations at specified locations, conditional upon certain assumptions. For example, emissions and plant parameters often must be estimated rather than measured, particularly in determining the magnitude of fugitive emissions and where there are large numbers of sources. This can lead to overestimates or underestimates of exposure. Similarly, meteorological data often are not available at the plant site but only from distant weather stations that may not be representative of the meteorology of the plant vicinity.

EPA's dispersion models normally assume that the terrain in the vicinity of the sources is flat. For sources located in complex terrain, this assumption would tend to underestimate the maximum annual concentration although estimates of aggregate population exposure would be less affected. On the other hand, EPA's benzene exposure models

assume that the exposed population is immobile and outdoors at their residence, continuously exposed for a lifetime to the predicted concentrations. To the extent that benzene levels indoors are lower and that people do not reside in the same area for a lifetime, these assumptions will tend to overpredict exposure.

Upon reconsideration, EPA has concluded that the presentation of the risk estimates as ranges does not offer significant advantages over the presentation as the associated point estimates of the risk. Further, the proposal ranges for benzene make risk comparisons among source categories more difficult and tend to create a false impression that the bounds of the risks are known with certainty. For these reasons, the benzene risks in this rulemaking are presented as point estimates of the leukemia risk. EPA believes that these risk numbers represent plausible, if conservative, estimates of the magnitude of the actual human cancer risk posed by benzene emitted from the source categories evaluated. For comparison, the proposal ranges may be converted into rough point estimates by multiplying the lower end of the range by a factor of 2.6.

The assumptions necessary to estimate benzene health risks and the underlying uncertainties have led some commenters on EPA's proposed rules to suggest that the risk estimates are inappropriate for use in regulatory decision making. Although EPA acknowledges the potential for error in such estimates, the Agency has concluded that both the unit risk factor for benzene and the evaluation of public exposure represent plausible, if conservative, estimates of actual conditions. Combining these quantities to produce estimates of the leukemia risks to exposed populations implies that the risk estimates obtained are also conservative in nature; that is the actual leukemia risks from benzene exposure are not likely to be higher than those estimated. In this context, EPA believes that such estimates of the health hazard can and should play an important role in the regulation of hazardous pollutants.

When the standard for benzene storage vessels was proposed on December 19, 1980, the Administrator made the judgment that "benzene emissions from benzene storage vessels create a significant risk of cancer and require the establishment of a national emissions standard under Section 112" (45 FR 83954).

The data base used to calculate emissions from storage vessels has changed since the standard was proposed. This change is based on new test data acquired since proposal. This data base and the reasons for using it are described in Section 2.2.2.1. Based on these new data, the emission estimates for fixed roof tanks (totally uncontrolled tanks) remains unchanged. The emission estimates for internal floating roof tanks and external floating roof tanks are lower than at proposal. Since a substantial proportion of existing tanks have internal or external floating roofs, this change resulted in a substantial reduction in the estimate of nationwide emissions from these tanks. For this reason, the Administrator reevaluated the need to establish Section 112 standards for benzene storage vessels.

Using the new emission data and a new exposure modeling approach adopted since proposal, the EPA estimated current leukemia cases and maximum lifetime risks that occur due to exposure from storage vessels, and the potential reductions that could be achieved to determine whether this source category continues to pose significant risk and whether a standard is warranted under Section 112.

Benzene storage vessels are currently estimated to emit about 620 Mg of benzene per year from about 126 storage facilities. This amount is about 1 percent of total benzene emissions from stationary sources. Estimated lifetime risk due to these emissions is about 3.6×10^{-5} for the most exposed individuals, and over the total exposed population (within 20 km of each facility) about 0.043 cases per year are estimated to occur.

For comparison, at proposal, the 126 facilities were estimated to emit about 2,200 Mg benzene per year. These benzene emissions were estimated to result in a range of 0.12 to 0.82 leukemia cases per year and a range of maximum lifetime risk of about 1.5×10^{-4} to 1.0×10^{-3}. Thus, since proposal, estimated benzene emissions have been revised downward by over 70 percent, estimated annual leukemia incidence by over 85 percent, and estimated maximum lifetime risk by over 90 percent.

Control measures that can be used to reduce benzene emissions include the use of certain types of equipment (much of which is already in place on many tanks in the industry), such as internal floating roofs, primary seals, and secondary seals, or enclosure of the storage

tanks and routing emissions to a combustion device (discussed at proposal). These control techniques could reduce nationwide emissions over baseline by about 18 to 98 percent, depending on the technique applied.

The current estimated leukemia incidence and maximum lifetime risk represent small risks to public health. By both expressions of health risk, the extent of the hazard posed by this source category is more than an order of magnitude smaller than for benzene source categories for which standards are being developed. Using the control techniques mentioned above, leukemia incidence could be reduced to roughly 0.036 to 0.0009 cases per year (about 16 to 98 percent reduction), and maximum lifetime risk to roughly 2.9×10^{-5} to 7×10^{-7}, (about 20 to 98 percent reduction). Although a large percentage reduction could be achieved in the health risks by enclosing, routing, and combustion, the absolute amount is small.

Because of the extent of control now exhibited by the industry, the small amount of benzene emissions from these sources and the small portion (about 1 percent) of the total benzene emissions from stationary sources that these sources represent, the small leukemia incidence and maximum lifetime risk estimated at current levels, and the small incremental reductions in these health risks achievable with available control techniques, the Administrator has concluded that benzene emissions from benzene storage vessels do not warrant Federal regulatory action under Section 112.

One commenter (IV-F-1) stated that the "risk levels that EPA has calculated are not 'significant' as that term has been used by the Court." EPA assumes that the commenter refers to the court interpretation in Industrial Union Department, AFL-CIO v. American Petroleum Institute, 65 L. Ed. 2d 1010, 100 S. Ct. 2844 (1980). This interpretation of the significance of risk was made in the context of The Occupational Safety and Health Act of 1970, not the Clean Air Act. It is not necessarily appropriate to transfer interpretations from one to the other. In any case, the Court in fact never indicated what actually constitutes a "significant" risk except to give obvious examples of what constitutes plainly acceptable and plainly unacceptable risks. The Court stated: "If, for example, the odds are one in a billion that a person will die from cancer by taking a drink of chlorinated water, the risk clearly

could not be considered significant. On the other hand, if the odds are one in a thousand that regular inhalation of gasoline vapors that are two percent benzene will be fatal, a reasonable person might well consider the risk significant and take appropriate steps to decrease or eliminate it" (48 LW 5034). The Court then stated that it was the duty of the OSHA Administrator to determine, using rational judgment, the relative significance of the risks associated with exposure to a particular carcinogen.

2.1.2 Storage Vessels Attached to Moving Vehicles

Comment: One commenter (IV-D-7) stated that definition of storage vessels should exclude storage vessels attached to mobile vehicles, such as tankers, barges and tank trucks.

Response: The control technologies that would be necessary to control benzene emissions from storage vessels attached to mobile vehicles, such as tankers, barges, or tank trucks, are completely different from those that are appropriate for other storage vessels. Additionally, data collection on tankers, barges, and tank trucks was not part of the survey performed by the EPA to develop a data base to support the Benzene Storage Vessel NESHAP. For these reasons, it was never the intent of the EPA to consider these types of benzene storage vessels as designated sources under this NESHAP.

2.1.3 Coke Oven Byproduct Vessels

Comment: One commenter (IV-D-15) stated that the regulations should not exempt tanks at coke oven by-product facilities. He felt that if benzene is hazardous, all facilities should be required to meet uniform control requirements.

Response: A separate NESHAP is currently being developed for coke oven by-product facilities. Vessels at coke oven by-product facilities were not incorporated into the benzene storage vessels source category because the applicable control techniques are different than the ones considered for this source category. This is a function of the nature of the coking and byproduct processes. For this reason, the Agency has decided that a separate standard for vessels at coke oven by-product facilities is appropriate and that such vessels should not be incorporated into these standards.

2.1.4 Benzene Mixtures

Comment: One commenter (IV-D-19) pointed out that the proposed standards would apply only to vessels that store pure benzene. He asked if vessels that store mixtures of benzene and other substances existed; and if so, why such vessels were not affected by these standards.

Response: It is true that vessels storing mixtures of benzene and other chemicals exist, but such vessels were never intended to be part of this source category. In part, this is because many vessels storing mixtures, such as those associated with coke oven byproduct processes, have different control options than those identified for this source category. The controls and impacts of control strategies for vessels storing mixtures would have to be examined as part of a separate source category. For this reason, the Agency decided not to extend the applicability of this source category to vessels storing benzene mixtures.

However, some information is currently available on vessels storing benzene mixtures, which for completeness will be presented here. There are three general classes of stored liquids that are composed of benzene that would not have been affected by the proposed standards. These are:

1. Liquids such as gasoline, which are stored in large quantities, but do not, on a fractional basis, contain more than 10 percent benzene;
2. Mixtures in which benzene may be more than 10 percent; and
3. Benzene that does not meet the specific gravity specification for industrial grade benzene (crude benzene).

New vessels storing gasoline (~2 percent benzene) are affected facilities under Standards of Performance for Petroleum Liquid Storage Vessels (40CFR60: Subpart K(a)). These standards discussed above require controls that are almost identical in effectiveness to those that were selected as BAT for new benzene storage vessels in the proposed NESHAP rule requirements. Many state implementation plans (SIPs) require that existing gasoline storage vessels be controlled to almost the same extent as the proposed BAT for existing benzene storage vessels.

Data were gathered on vessels storing liquids of the second class (Table 2-2). This data was obtained from a data base of 4,054 vessels associated with the Synthetic Organic Chemical Manufacturing Industry (SOCMI). Fifteen (15) were thought to possibly contain more

Table 2-2. VESSELS CONTAINING MIXTURES THAT MAY BE MORE THAN 10 PERCENT BENZENE[a]

Vessel contents	Volume (1000's of gallons)
Benzene Caprolactum	4.4
Benzene Lactum	7
Benzene/Toluene	37.8, 237, 42, 8.8, 17.0, 1272.7[b]
EA, Benzene, Water	2, 2, 2[b]
EA, Benzene	4.75
Light Aromatic Distillate	515, 515, 63.5[b]

[a]Including crude benzene.

[b]Multiple vessels with same contents.

than 10 percent of benzene. The total volume of these vessels is about 2.7 million gallons. This can be compared to the estimated 500 vessels with a total volume of about 308 million gallons that stored industrial grade benzene in 1979. The total tank volume (tankage) devoted to the storage of this type of benzene mixtures is less than one percent of the tankage devoted to benzene. Because vessels storing mixtures will have reduced amounts of benzene in them, the true amount of benzene stored may be significantly reduced from the above two million gallons.

The last class of liquids consists of unfinished (crude) benzene or off specification benzene. Most such liquids are petroleum liquids and many are affected facilities under Subpart K(a) or the SIPs and as such, would be controlled to some extent. There was only one such tank in the data base.

2.2 HEALTH AND ENVIRONMENTAL IMPACTS

2.2.1 Background

The proposed standards, which were based on Best Available Technology (BAT), would have required the use of a fixed roof in combination with an internal floating roof. The proposed standards also would have required that the internal floating roof be in contact with the liquid surface and be equipped with a liquid-mounted primary seal and a continuous secondary seal.

Many commenters suggested that the EPA delay the development of the final standards until the effectiveness of BAT equipment relative to other equipment types could be reevaluated using data from the American Petroleum Institute (API) 2519 Task Group testing program. The results of this testing program have been received and evaluated by the EPA. Comments were also received on other aspects of BAT, such as control equipment costs.

2.2.2 Selection of the Level of the Standard

2.2.2.1 Emission Data Base. Seven commenters suggested that the emissions data base used in selection of the BAT at proposal was erroneous and that the Agency should await the completion of a new API testing program before selecting BAT prior to promulgation (IV-D-1, IV-D-2, IV-D-3, IV-D-8, IV-D-10, IV-D-10a, IV-D-14).

Response: There are four potential emission data bases from which emission calculations could be developed. These are:

1. A test series done by Chicago Bridge and Iron (CBI) for an internal floating roof vendor. This series measured emissions from a bolted, noncontact internal floating roof equipped with wiper-type, vapor-mounted primary seals; and a welded contact internal floating roof. The welded roof was equipped with a liquid-mounted primary seal and in some instances a secondary seal. All the tests were performed in a propane/octane binary mixture. This data base is hereafter referred to as the Vendor report or series.
2. A large number of tests done on various external floating roofs with propane/octane as the stored liquid. These tests were also performed by CBI. The primary emphasis of this work was to categorize emissions from various types of primary and secondary seals and was used to update API bulletin 2517, which is used in estimating emissions from external floating roof tanks. It was also used in the 1981 revision of EPA publication AP-42. This work is referred to as the 2517 series or report.
3. A test series done by CBI for the EPA using benzene as the test liquid. This program tested a bolted noncontact internal floating roof with vapor-mounted, shingled, primary and secondary seals; a welded contact type internal floating roof equipped with a liquid-mounted primary seal and in some instances, a secondary seal; and an external floating roof equipped with a mechanical shoe primary seal and in some instances a secondary seal. This data base will be referred to as the EPA report or series.
4. A test program done by CBI for API on emissions from internal floating roofs. This program tested three roof types (non-contact, bolted contact, welded contact), three primary seal types (vapor-mounted wiper; vapor-mounted, foam-filled resilient seal; liquid-mounted seal) with and without secondary seals, in three different liquids (propane/octane, hexane, and octane). Additional work was done on emissions from the components of

an internal floating roof. This consisted of deck fitting emission tests, laboratory evaporation tests, laboratory permeability tests, and bench permeability tests. This data base will be referred to as the 2519 report or series.

Each of the above test series was performed in the CBI 20 foot diameter pilot test tank. The first three were completed prior to the development of the proposed standards, but the 2519 series was completed after the date of proposal.

In evaluating the emissions data for internal and external floating roofs prior to proposal it was noted that emissions from the EPA series were significantly higher than those measured in either the Vendor or the 2517 series when tests on similar equipment were normalized to the same vapor pressure and molecular-weight. The Agency believed that the difference in emissions resulted from a difference in liquids, namely multicomponent liquids such as propane/octane and single component liquids such as benzene. The reason for this difference was believed to be due to that fact that in a mixed product (e.g. the propane/octane mixture) the emission rate depends upon the ability of the component with the highest partial pressure (e.g. propane) to migrate through the liquid to the liquid surface and replenish the component that is lost through evaporation at the liquid surface. In a single component product (e.g. benzene), however, the liquid surface does not tend to become depleted of light ends at the liquid surface during the evaporation process. Thus, a mixed product of the same vapor pressure as a single component product was expected to have a lower evaporation rate due to this phenomenon. Therefore, in selecting BAT at proposal only the EPA test series was used because it was believed that the previous propane/octane test work was not representative of single component emissions such as a vessel storing benzene.

Industry representatives commented that the higher emissions were a result of the test procedures and did not necessarily result from a difference in evaporative properties. The 2519 test series shows that when normalized to a common vapor pressure and molecular weight, there is no significant emission difference between hexane, octane, and the propane/octane binary mixture. Based on these results the Agency now agrees that there is no evidence of evaporative difference between

single and multicomponent liquids stored in floating roof tanks, and this is not a reason for the higher emissions measured in the EPA series.

One cause of at least a portion of the higher emissions from the EPA series is that during certain internal roof tests done for the EPA series, the roof fittings had openings that would not normally exist in the field and were sealed with polyurethane film, which, as previously discussed, is permeable to benzene. This would lead to artificially higher emissions being measured during the EPA series than would normally be expected from a typical field tank. During tests done on the same roof for the 2519 series the roof fitting openings that would not normally exist in the field were sealed by welded metal seals not permeable to benzene. This procedure would yield measured emissions more representative of emissions from a typical field-located tank.

Also during the EPA series, the bolted noncontact internal floating roof was tested with shingled (i.e., noncontinuous) primary and secondary seals, which are not as effective in reducing emissions as the more typical continuous wiper or foam-filled resilient seals. This again would lead to higher emissions being measured during the EPA series. Either wiper or foam-filled resilient seals were tested during the other test series.

Other physical mechanisms that could explain the higher emissions in the EPA series were sought. The permeability results in the 2519 series were examined to ascertain if permeation of the seal system could be responsible for the higher benzene emission. As detailed in Appendix A, the permeation rate of benzene through a typical seal fabric (polyurethane) was significantly higher than the rates at which hexane or propane/octane permeate. Because there are no direct measurements of benzene permeation rates through an entire seal system, theoretical models were developed. The most reasonable model of permeation through a liquid-mounted seal predicts emissions of 0.0102 pound moles per day in the test tank (see Appendix A). While permeation and equipment differences may explain some of the emission differences between the benzene test work and the other test work, it is not sufficient to account for the total difference.

Another explanation of the higher emissions from floating roof tanks shown by the EPA series, has to do with the test procedures used. The vendor series and the 2517 series used the same test procedure as

the EPA series, that is, a floating roof and seal system is installed in the pilot tank, and air is blown over the floating roof. The air is collected and analyzed for hydrocarbon content. In the vendor, 2517, and EPA series test work, the temperature of the air being blown across the roof was uncontrolled. During periods when the air is cold (such as during the winter), the benzene vapor being emitted will condense during periods when actual tests are not being run. When a test is then begun, the benzene vapor that condensed will be measured during the test when it was actually emitted before the test run began. In the case of benzene (EPA series) this could lead to artificially higher results. In the case of the propane/octane mixture, the uncontrolled air temperature is not as important to the results since this mixture is less likely to condense in the cold air. In the 2519 series, the air temperature was controlled, and no emissions differences were observed between the three tested liquids.

As just explained, because the 2519 series test conditions were more controlled than during the EPA series and because of the equipment tested (continuous versus shingled seals), this test series resulted in more representative emission measurements. The 2519 series was also structured to make it possible to ascertain more accurately the relative contributions to emissions of the various emission points (e.g., seals, roof seams and roof fittings). Also, the data obtained from the 2519 series are similar to the vendor series that tested similar roofs and seals and used a propane/octane binary mixture.

The higher permeability of benzene, the difference in equipment tested and the differences in test procedures explain most of, but not all, the higher emissions from floating roof tanks measured during the EPA series. Currently, however, there is no explanation beyond what has already been discussed as to why benzene emissions would be any higher than the hexane and octane emissions measured during the tests done in the 2519 series.

Since there is no reason (other than possibly permeability, which is addressed later) for benzene emissions (normalized for vapor pressure and molecular weight) to be higher than hexane and octane emissions during the 2519 tests, and since the 2519 series was conducted with more refined procedures and more thoroughly evaluated the emission sources

and control techniques for each source, the Agency has decided to use the data from this series to evaluate the emission reduction potential for various control technologies applied to fixed roof and internal floating roof tanks. For similar reasons, the Agency has selected the 2517 series as the data base for evaluating controls for external floating roof vessels. The 2517 tests are more extensive in terms of equipment tested and, for the same reasons as the 2519 series, have measured emissions more representative of emissions from a typical external floating roof.

Table 2-3 compares emissions from selected floating roof tank types as calculated using data from the EPA series and as calculated using data from the 2519 and 2517 series. It should be noted that because of differences in tested equipment and test procedures, the emissions are not strictly comparable. However, it can be seen that the sharp difference in emissions (particularly in terms of mass rather than percentage) between the equipment configurations vanished in the 2519 and 2517 test series. Making the decision that the 2517 and 2519 test series are superior to the EPA test series meant that it was then necessary to reexamine baseline impacts and effectiveness of control techniques for benzene storage vessels.

The Agency examined the emission points from possible baseline tank types and possible control technologies. As explained in the Volume I BID there are four types of tanks that could be used to store benzene. These are:

1. Fixed roof tanks;
2. Noncontact internal floating roof tanks;
3. Contact internal floating roof tanks; and
4. External floating roof tanks.

Based on the 2519 test series, there is no inherent difference between contact and noncontact deck types. Analysis of the data concluded that deck seams emit at the same rate if they are in contact with the liquid or saturated vapor. Contact decks may be welded (i.e., no deck seams) or bolted (e.g., mechanically connected panels or sections that have seams). A bolted contact deck would have deck seam emissions at the same rate per foot of deck seam as a noncontact deck. Because of this, for the purpose of evaluating control efficiencies the two types of

Table 2-3. COMPARISON OF EMISSIONS AS CALCULATED FROM THE EPA SERIES AND THE 2519/2517 SERIES

Tank type/equipment	Test series: EPA emissions (Mg/yr)	Test series: 2517/2519 emissions (Mg/yr)
I. Internal Floating Roof		
A. Bolted deck with vapor-mounted primary and secondary seals	3.56[1]	0.42[2]
B. Welded deck with liquid-mounted primary seal	1.15	0.38
C. Welded deck with liquid-mounted primary and secondary seals	0.67	0.34
II. External Floating Roof with Mechanical Shoe Primary Seal		
A. Primary seal only	6.99	1.11
B. With rim-mounted secondary	2.63	0.087

[1]Both primary and secondary seals were shingle design.

[2]All seals were continuous.

internal floating roofs were merged into the general classification of internal floating roof. This procedure reduced the basic starting cases to three tank types: fixed roof, internal floating roof (bolted deck assumed), and external floating roof.

The mechanisms of fixed roof tank and external floating roof tank emissions have been fully discussed in the Volume I BID. Although the external floating roof tank emission factors have changed based on the 2517 series, the emission mechanisms are still the same. Fixed roof tank emissions have not changed since proposal.

The 2519 series allows for a more detailed breakdown of internal floating roof tank emissions into:

1. Standing storage losses, consisting of:
   a. Rim seal emissions;
   b. Fitting losses; and
   c. Deck seam emissions
2. Working losses.

Table 2-4 presents losses from a model benzene storage vessel by point of loss, and Table 2-5 compares emissions from various selected tank configurations. The model tank, used in these calculations and all subsequent calculations in this section, has a volume of 606 m^3 (160,000 gallons), a diameter of 9.1 m (30 feet), and undergoes 50 turnovers per year.

Internal floating roofs are typically bolted decks equipped with vapor-mounted seals and Case A fittings (defined below). In the model tank, emissions from the vapor-mounted seal are about 35 percent of total emissions. Emissions from the vapor-mounted seal could be reduced through the use of a liquid-mounted primary seal, a secondary seal, or both. A liquid-mounted seal reduces emissions from the vapor-mounted primary seal by about 55 percent. The addition of a secondary seal to the vapor-mounted primary seal would reduce emissions by about 63 percent. The addition of a secondary seal to a liquid-mounted primary seal reduces emissions by about 46 percent over the liquid-mounted primary seal alone. Converting a vapor-mounted primary seal system to a liquid-mounted primary seal with a secondary seal reduces emissions from the seal area by about 76 percent over the vapor-mounted primary seal alone.

Table 2-4. INTERNAL FLOATING ROOF TANK EMISSIONS BY SOURCE[1]

Seal losses		Fitting losses		Deck losses		Working losses
Type	Emission (Mg/yr)	Case	Emission (Mg/yr)	Roof type	Emission (Mg/yr)	Emission (Mg/yr)
Vapor-mounted	0.19	A[2]	0.26	Bolted	0.06	0.03
Liquid-mounted	0.085	B[3]	0.16	Welded	0.0	
Vapor-mounted with secondary	0.071	C[4]	0.19			
Liquid-mounted with secondary	0.046					

[1]Tank Parameters: Volume = 160,000 gallons
Diameter = 30 feet
Turnovers = 50 turnovers per year

[2]Case A assumes: (1) access hatch, with ungasketed, unbolted cover; (2) automatic gauge float well, with ungasketed, unbolted cover; (3) built-up column wells, with ungasketed sliding cover; (4) ladder well, with ungasketed sliding cover; (5) adjustable roof legs; (6) sample well with slit fabric (10% open area); (7) 1-inch diameter stub drains; and (8) vacuum breaker with, gasketed weighted mechanical actuation.

[3]Case B assumes: (1) access hatch, with gasketed, bolted cover; (2) automatic gauge float well, with gasketed, bolted cover; (3) pipe column with flexible fabric sleeve seal; (4) ladder well, with gasketed sliding cover; (5) adjustable roof legs; (6) sample well with slit fabric (10% open area); (7) 1-inch diameter stub drains; and (8) vacuum breaker, with gasketed weighted mechanical actuation.

[4]Case C is identical to Case B except that built-up columns with gasketed sliding covers are assumed instead of pipe columns.

Table 2-5. EMISSIONS FROM A TYPICAL BENZENE STORAGE VESSEL

Tank type/equipment	Emissions (Mg/yr)
I. Fixed Roof	9.2
II. Internal Floating Roof	
A. Bolted deck, vapor-mounted seal, Case A fittings	0.54
B. Bolted deck, liquid-mounted Case A fittings	0.44
C. Bolted deck, liquid-mounted seal, Case B fittings	0.34
D. Bolted deck, liquid-mounted primary with secondary, Case B fittings	0.30
E. Welded deck, liquid-mounted primary with secondary, Case B fittings	0.24
III. External Floating Roof	
A. Mechanical Shoe Primary Seal	1.11
1. Primary seal only	
2. With rim-mounted secondary	0.087
B. Vapor-mounted Primary Seal	6.9
1. Primary seal only	
2. With rim-mounted secondary	2.31
C. Liquid-mounted Primary Seal	0.36
1. Primary seal only	
2. With rim-mounted secondary	0.080

The next major source of internal floating roof tank emissions are losses from fittings. Fittings in general are ancillary equipment such as hatches or column wells that penetrate the deck. Such penetrations will emit benzene. Typical fittings are: (1) access hatch, with ungasketed, unbolted cover; (2) automatic gauge float well, with ungasketed, unbolted cover; (3) built-up column wells, with ungasketed sliding cover; (4) ladder well, with ungasketed sliding cover; (5) adjustable roof legs; (6) sample well with slit fabric (10% open area); (7) 1-inch diameter stub drains; and (8) vacuum breaker with, gasketed weighted mechanical actuation. This equipment is referred to as "Case A". In the model tank, emissions from Case A fittings account for about 48 percent of total emissions. Emissions from Case A type fittings could be reduced through the use of gaskets, bolting covers, and constructing pipe columns with flexible fabric sleeve seals on the column well in place of built-up columns equipped with ungasketed sliding covers in the column wells. This configuration of fittings is referred to as Case B and is the level of control that could be obtained in new benzene storage vessels equipped with internal floating roofs. Specifically, "Case B" is defined as: (1) access hatch, with gasketed, bolted cover; (2) automatic gauge float well, with gasketed, bolted cover; (3) pipe column wells with flexible fabric sleeve seal; (4) ladder well, with gasketed sliding cover; (5) adjustable roof legs; (6) sample well with slit fabric (10% open area); (7) 1-inch diameter stub drains; and (8) vacuum breaker, with gasketed weighted mechanical actuation. Case B fittings would reduce emissions from the typical fittings Case A by about 38 percent.

Existing internal floating roof benzene tanks typically use built-up columns to support the fixed roof. Such vessels could not be equipped with pipe columns without replacing the columns. In most instances, this would be equivalent to requiring the construction of a new tank. Therefore, an intermediate control strategy was sought. Emissions from built-up column wells could be controlled by gasketing the sliding cover. This strategy is referred to as "Case C" and represents the level of fitting control available in existing internal floating roof tanks.

Specifically, Case C is identical to Case B except that built-up columns with gasketed sliding covers are assumed instead of pipe columns. Case C fittings would provide about a 27 percent emission reduction over Case A fittings. Because most existing fixed roof benzene tanks are equipped with built-up columns, Case C represents the level of control of fitting emissions generally available for existing tanks.

The next source of internal floating roof tank emissions are deck seams. Decks that are constructed of sections bolted together have emissions along the seam. As discussed previously, seams emit at the same rate if they are in contact with the liquid surface (contact deck) or contain a saturated vapor on one side (noncontact deck). Because of this fact, the distinction between contact and noncontact decks has been dropped, and these decks are now referred to as "bolted" for emission purposes. Emissions from the deck seams in the model tank are about 11 percent of total emissions.

Deck seam emissions could be controlled by installing decks that have no seams. Such decks are generally made out of steel sections welded together. These decks are generally in contact with the liquid surface, and are referred to as "welded" for emission purposes.

The last emission type in an internal floating roof tank is the working loss. These losses are fully discussed in the Volume I BID and account for about 6 percent of typical losses. No controls for working losses are available.

As Table 2-5 shows, fixed roof tank emissions could be reduced by about 94 percent by the installation of internal floating roofs. Emissions could be further reduced through the use of additional controls on seals, fittings, and deck seams.

Emissions from external floating roofs could be reduced by the addition of a secondary seal over the primary seal. In the case of the mechanical shoe primary seal, this would reduce emissions by about 92 percent. Emissions from vapor-mounted primary seals could be reduced by replacing these seals with mechanical shoe seals or liquid-mounted primary seals alone or further reduced with secondary seals.

In examining the effectiveness of the control techniques based on the 2519 and 2517 test series, it was noted that the emission reductions for these techniques based on the 2519 and 2517 test series are quite

different than those calculated at proposal. For example, the 2519 series showed that the control effectiveness of an internal floating roof (of any type) in a fixed roof tank is much more effective in reducing emissions than was believed at proposal, based on the EPA test series. On the other hand, the 2519 test series showed that a secondary seal in an internal floating roof tank is much less effective in reducing emissions than believed at proposal based on the EPA test series. This is to be expected because the internal floating roof is more effective than believed previously and as a result, there are less residual emissions to be controlled by the secondary seal. The 2519 test series showed that contact and noncontact roofs are equally effective in reducing emissions. The 2519 test series also showed that liquid-mounted seals are more effective in reducing emissions than vapor-mounted seals. This type of seal can be used with both contact and noncontact roofs and was considered as a control technique. Furthermore, the 2519 series showed that control of roof fittings, column wells, and roof deck seams does reduce emissions. Using the 2517 and 2519 data in combination shows that external floating roofs can, when used with effective seals, reduce emissions as effectively as internal floating roofs.

As briefly mentioned previously, there is an additional source of emissions that has not been fully considered up to this point. This is the permeability of seal systems and gaskets to benzene. The 2519 series and the open literature point to the fact that aromatics such as benzene have higher permeability rates through polymers than some other types of compounds. Because no direct measurements of seal permeability are available, the Agency examined this emission source by developing theoretical models.

These models represented:

1. A foam-filled liquid-mounted seal;
2. A wiper type, vapor-mounted primary seal; and
3. Each of the above with a wiper type secondary seal.

Each seal consists of two parts:

1. Two layers (top and bottom) of seal fabric; and
2. Open cell foam situated between the fabric layers.

In selecting the fabric layers for modeling, it was discovered that there was little data on what fabrics are actually in use, and little

data on measured fabric permeability rates. Because the Agency had permeability measurements on 0.037 inch thick polyurethane-coated nylon fabric from the 2519 tests, and because this material is currently in use in field tanks, the Agency decided to use this material as the fabric in the models.

In modeling the open cell foam it was assumed that the foam presented no permeability barrier. Transport between the fabric layers was assumed to be diffusion (it was assumed that the foam did not allow convective transport). These models done on a 20 foot diameter tank are contained in Docket Item IV-A-1. For the purpose of comparability to the model tank (30 foot diameter) emissions the results have been extrapolated to the model tank.

Table 2-6 compares the convective losses presented in Table 2-4 with the calculated permeability losses. It is seen that permeation may account for more than 50 percent of seal losses if:

1. The permeation rates are correct; and
2. The models realistically represent actual systems.

Table 2-7 examines how consideration of permeability affects the overall effectiveness of controls compared to a fixed roof tank. The reduction in overall effectiveness when permeability is considered is less than 3 percent.

However, the Agency examined how permeability emissions may be controlled. These emissions could be controlled by a seal permeability specification. Such a specification would limit permeability emissions to a specified limit per unit area of seal. However, the variation in measured values in open literature indicate that such measurements would be difficult to make reliably. Seal materials must withstand abrasion and flexing as the floating roof moves. At this point in time, the Agency is aware of no materials or laminar composites that would have both the necessary characteristics of material strength and permeation rates lower than the modeled fabric. Such a specification could be made with additional research on materials.

Table 2-8 shows revised baseline emissions based on the revised emission equations for each of the four model plants developed during proposal. Table 2-9 shows revised baseline nationwide emission estimates based on the revised emission equations.

Table 2-6. COMPARISON OF CONVECTIVE AND PERMEABILITY LOSSES FROM INTERNAL FLOATING ROOF SEAL SYSTEMS IN THE MODEL TANK

Seal type	Emissions (Mg/yr)		
	Convective	Modeled permeation	Possible total losses
Vapor-mounted	0.19	0.21	0.40
Liquid-mounted	0.085	0.20	0.285
Vapor-mounted with secondary	0.071	0.11	0.181
Liquid-mounted with secondary	0.046	0.10	0.146

Table 2-7. MODEL TANK EMISSIONS (Mg/yr) FROM A FIXED ROOF TANK AND A TYPICAL INTERNAL FLOATING ROOF TANK

Tank type	Emission	Percent control
Fixed roof	9.2	—
Internal floating roof with bolted deck, Case A fittings, vapor-mounted primary seal only, no permeability	0.54	94.1
Internal floating roof with bolted deck, Case A fittings, vapor-mounted primary seal, permeability	0.75	91.8

Table 2-8. EMISSIONS FROM NEW AND EXISTING MODEL PLANTS

Tank dimensions (meters x meters)[a]	Emissions (Mg/y)	
	Existing	New
Large benzene producer		
12 x 9	0.72	0.72
18 x 12	2.19	0.13
8 x 5	0.48	0.48
9 x 9	0.59	0.59
13 x 13	0.68	0.68
24 x 9	1.36	1.36
27 x 15	1.82	1.82
Total	7.84	5.78
Small benzene producer		
3 x 11	1.27	1.27
13 x 13	0.68	0.68
8 x 11	0.50	0.50
32 x 7	2.17	2.17
Total	4.61	4.61
Benzene consumer		
12 x 11	0.64	0.64
18 x 15	0.97	0.97
Total	1.61	1.61
Bulk storage terminal		
12 x 11	0.64	0.64
18 x 15	0.97	0.97
Total	1.61	1.61

[a]Diameter x height.

Table 2-9. NATIONWIDE EMISSIONS FROM NEW AND EXISTING BENZENE STORAGE TANKS

Model plant	Emissions (Mg/y)	
	Existing	New[a]
Large benzene producer	269	55
Small benzene producer	192	53
Benzene consumer	152	42
Bulk storage terminal	8	2
Total	621	152

[a]Fifth-year (1988).

2.2.3 Exposure Assessment

A number of commenters (IV-D-1, IV-D-3, IV-D-4, IV-D-10, IV-D-10a, IV-D-13, IV-D-21, IV-F-1) stated that the model plant methodology used by the EPA overestimates risk from benzene exposure. The commenters suggested that a more realistic and accurate risk estimate would be obtained using actual plant emission data, actual population data, and available plant-specific emission data.

One commenter (IV-D-10a) maintained that the Agency's benzene emissions exposure analysis relied upon incomplete and inaccurate meteorologic data. Rather than use site-specific climatological data as required by the Agency guidelines, the commenter remarked that the analysis relies entirely on conditions at the Gulf Coast to apply to storage vessels throughout the nation.

According to the commenter, the EPA concedes that this assumption causes an overstatement of estimated exposure, noting its data were "representative of poor dispersion conditions in the area in order to develop a potential worst-case situation". He concluded that since climatological data for approximately 300 sites throughout the U.S. are available in the Agency archives, the EPA's total reliance on Gulf Coast meteorology was not justified. The commenter also stated that the EPA arbitrarily oriented the benzene storage vessels of a hypothetical facility in order to maximize the ambient concentrations at the plant boundary. According to the commenter, this was done despite the fact that the actual storage vessels are not usually arranged in a straight line configuration.

The commenter further asserted that the EPA failed to validate the results of its air quality modeling as a check on its accuracy, as required by Agency guidelines. According to the commenter, in this exposure analysis, the EPA repeatedly has relied upon unsupported assumptions about emissions, meteorology, population distribution, and other factors, even though accurate data were readily available. The approach taken results in an unacceptably high degrees of uncertainty in the Agency's exposure estimates; in some instances, the exposure estimate may be off by a factor of 100 or more.

Response: The commenter is correct in noting that the benzene storage risk assessment did not make use of plant-specific data relating

to emissions, meteorology, or plant configurations. However, as explained below, the plant-specific approach probably would not improve the precision or accuracy of the results enough to justify the level of effort to use more specific data. EPA has concluded that a plant-specific approach would be too costly and not necessary for benzene storage emission sources. In response to this comment, the EPA has revised its original risk assessment for benzene storage vessels: the unit risk factor has been recalculated; new emission estimates have been developed based on the new API data; the meteorology of the area where each plant is located has been used; and an improved population model (Human Exposure Model) has been used.

The EPA considered the option of using plant-specific data for all parameters in order to run an exposure model for each plant. The EPA compared the uncertainty that would result using the plant-specific data approach with the uncertainty that would result using the model plant and extrapolation approach. The EPA also compared the level of effort that would be required to complete the two options.

The plant-specific approach probably would not improve the precision or accuracy of the results enough to justify the level of effort required to gather the input data. A plant-specific approach would entail using "Section 114" letters to gather plant information on emissions, meteorology, and plant configuration from about 130 plants. This would require substantial effort from plant owners as well as from the EPA. The dispersion and exposure models would then have to be run about 130 times, at least once for each plant. The resultant increase in precision and accuracy would probably be small compared to the uncertainty still remaining that is inherent in the dispersion and exposure models and in the input data used. Both the Industrial Source Complex Long Term computer model (ISCLT) and the Human Exposure Model, even with perfect input data, are subject to substantial uncertainty. (The ISCLT model, even with state-of-the-art input data, is estimated to have a 95 percent confidence interval of plus or minus a factor of two.) The plant-specific input data would also exhibit wide variability and thus introduce uncertainty in the results of the study.

The Agency has not exaggerated the precision of the results of the model plant extrapolation method, nor has the EPA attempted to refine

the results of the model plant extrapolation method any more than is warranted by the quality of the data and the modeling technique. Uncertainties are clearly delineated. The results are presented in highly aggregate, nonspecific terms, in a fashion that exhibits much less uncertainty than if the EPA tried to obtain more detailed, refined results from the extrapolation. Using the model plant extrapolation method, inaccurate deviations in the results for specific plants tend to average out when the total national incidence is computed. Attempting to validate the results of the air quality modeling would require an extremely detailed, burdensome, and costly plant-specific approach. Because a plant-specific approach would be very costly and would not substantially improve upon the precision and accuracy already achieved by the model plant extrapolation approach, the EPA has elected to use the model plant extrapolation approach.

Comment: One commenter (IV-D-10a) added that deficiencies exist in the population concentration estimates contained in the exposure analysis. According to the commenter, the EPA assumed that population is distributed uniformly in all directions at each site, which introduces an uncertainty factor of 10 to 100 into the overall exposure estimate.

Response: EPA's revised risk estimate (see Appendix B) was based upon a more sophisticated population exposure model, which utilized a population data base characterized as having a high level of resolution. The Human Exposure Model (HEM) was used to estimate the population that resides in the vicinity of each receptor coordinate surrounding each plant. The HEM does not assume population is distributed evenly around each plant. The population "at risk" to benzene exposure was considered to be persons residing within 20 km of the plants. The population around each plant was determined by specifying the geographical coordinates of that plant.

A slightly modified version of the "Master Enumeration District List--Extended (MED-X)" data base, a Census Bureau data base, is contained in the HEM and used for population pattern estimation. This data base is broken down into enumeration district/block group (ED/BF) values. MED-X contains the population centroid coordinates (latitude and longitude) and the 1970 population of each ED/BG in the United States (50 states plus the District of Columbia). For human exposure estimations, MED-X

has been used to produce a randomly accessible computer file of only the data necessary for the exposure estimation. A separate file of county-level growth factors, based on the 1970 to 1980 growth factor at the county level, has also been created for use in estimating 1980 population figures for each ED/BG.

The plant's geographical coordinates and the concentration patterns computed by the model plant extrapolation method were used as input to the HEM. For each receptor coordinate, the concentration of benzene and the population estimated by the HEM to be exposed to that particular concentration are identified. The HEM multiplies these two numbers to produce population exposure estimates and sums these products for each plant. A two-level scheme has been adopted in order to pair concentrations and populations prior to the computation of exposure. The two-level approach is used because the concentrations are defined on a radius-azimuth (polar) grid pattern with nonuniform spacing. At small radii, the grid cells are much smaller than ED/BG's; at large radii, the grid cells are much larger than ED/BG's. The area surrounding the source is divided into two regions, and each ED/BG is classified by the region in which its centroid lies. Population exposures are calculated differently for the ED/BG's located within each region.

For ED/BG centroids located between 0.1 km and 2.8 km from the emission source, populations are divided between neighboring concentration grid points. There are 96 (6 x 16) polar grid points within this range. Each grid point has a polar sector defined by two concentric arcs and two wind direction radials. Each of these grid points is assigned to the nearest ED/BG centroid identified from MED-X. The population associated with the ED/BG centroid is then divided among all concentration grid points assigned to it. The exact land area within each polar sector is considered in the apportionment.

For the population centroids between 2.8 km and 20 km from the source, a concentration grid cell, the area approximating a rectangular shape bounded by four receptors, is much larger than the area of a typical ED/BG (usually 1 km in diameter). Since there is a linear relationship between the logarithm of concentration and the logarithm of distance for receptors more than 2 km from the source, the entire population of the ED/BG is assumed to be exposed to the concentration

that is geometrically interpolated radially and azimuthally from the four receptors bounding the grid cell. Concentration estimates for 80 (5 x 16) grid cell receptors at 2.0, 5.0, 10.0, 15.0 and 20.0 km from the source along each of 16 wind directions are used as reference points for this interpolation.

In summary, two approaches were used to arrive at coincident concentration/population data points. For the 96 concentration points within 2.8 km of the source, the pairing occurs at the polar grid points using an apportionment of ED/BG population by land area. For the remaining portions of the grid, pairing occurs at the ED/BG centroids themselves, through the use of log-log linear interpolation.

Comment: A commenter (IV-D-10a) stated the analysis failed to account for population activity patterns and population mobility, thereby overestimating exposure levels for persons residing in the affected area surrounding these plants. He further criticized the EPA's estimate of "maximum individual lifetime risk" by noting that the Agency has no evidence that any individual ever lives an entire lifetime 0.1 kilometers from the plant at a point of maximum benzene concentration.

Response: The maximum individual lifetime risk, as the commenter understood, is the risk associated with exposure to the maximum concentration. Maximum concentrations are only modeled estimates and may overestimate or underestimate the actual concentrations. As discussed in Docket Item IV-B-4, the maximum concentrations and, consequently, the maximum individual lifetime risks (which were estimated and used to make, to the limited extent they were used, decisions) appear to be underestimates. Provided the air at 0.1 kilometer from plant is located in a neighborhood, the opportunity for exposure exists. Using the HEM, exposures to maximum concentrations are generally limited to distances greater than 0.2 kilometer and to locations where people reside. In the absence of perfect information regarding the magnitude and duration of exposure, it is prudent to assume that, as a "maximum", an individual could face continuous exposure to a maximum concentration.

Comment: One commenter (IV-D-19) felt that the EPA had understated the risk of exposure to benzene storage emissions. According to one commenter, the scientific knowledge necessary for reasonably reliable and precise estimates of human cancer risks simply is not available.

The commenter felt that, given interactions and synergisms, it is much more likely that exposure to multiple chemicals will have an additive or multiplicative effect than that such chemicals will cancel each other out. This commenter cited many sources of uncertainty in the risk assessment and concluded that the EPA may have drastically understated the real leukemia risk associated with benzene. According to the commenter, the estimates given by the EPA may well underestimate the health benefits of the increment between the proposed requirements and use of vapor recovery or thermal destruction of emissions. He added that it is unacceptable that the noncarcinogenic effects of benzene exposure have virtually dropped out of the EPA's analysis due to the fact that they cannot be readily quantified. According to the commenter, the proposal makes no efforts to see that these effects get appropriate weight in the decision to stop short of more stringent regulatory alternatives.

Response: While the commenter may be correct that interactions and synergisms (resulting from exposures to multiple chemicals) may be additive or multiplicative (or antagonistic) and therefore result in truly greater (or smaller) risks to persons exposed to benzene, EPA is unable to estimate these effects and, therefore, has not considered them. It should be noted that many of the factors used in making the exposure assessment have uncertainties associated with them and that these uncertainties can result in underestimation as well as overestimation. These uncertainties are described in a previous response (2.1.2) and have been considered as much as is practicable by EPA in the decision to withdraw the proposed standards.

Comment: A commenter (IV-D-19) noted that the EPA assumed that many benzene-emitting facilities have a life expectancy of 50 years or more. Yet the quantifications of risk used to compare the proposed approach with a more protective one, assume a 20-year lifetime. According to the commenter, this understates the number of benzene victims for such facilities by two and one-half times or more, and reconsideration of the decision not to adopt Alternatives IV or V (at proposal) with the appropriate health effects timeframe may lead to a different decision (IV-D-31).

Response: Twenty years is an average figure for the lifetime of a plant. Some plants have a life expectancy of 50 years; some have lifetimes

shorter than 20 years. Roughly, a plant will have a lifetime of 20 years. Since there are little data available that estimate plant lifetimes, the EPA considers 20 years to be a reasonable estimate. However, the EPA agrees there is uncertainty associated with this number.

2.2.4 Risk Methodology Consistency

Comment: A number of commenters (IV-D-10a, IV-D-4, IV-F-1) stated that there should be some consistency in risk assessment methodologies between the four current benzene proposals. One commenter stated that if benzene is to be regulated by a NESHAP standard, the emission concerns and risk/benefit analysis should be completed for all types of emissions (e.g., process emissions, storage tank emissions, fugitive emissions, etc.) simultaneously. This integrated analysis, the commenter maintained, would prevent duplication of effort, errors, or inconsistencies and result in an overall analysis of the risk/benefit of a product. According to another commenter's (IV-D-21) review of the four current benzene proposals, a great deal of duplication has occurred with little or no health benefit to the public.

Response: The risk assessment methodologies used in evaluating the four source categories for which benzene standards have been proposed have been made more consistent. The only area in which they are different is that the affected industries voluntarily submitted detailed plant-specific information on the maleic anhydride and ethylbenzene process vents. Obtaining this kind of information for the 126 or more plants that have benzene fugitive and storage sources would be too costly (considering the uncertainty of the final results either way) for the industry or the EPA to obtain. Because of the detailed information available on maleic anhydride and ethylbenzene/styrene process vents and the relatively small number of these plants, the more precise ISC dispersion model was used for all those plants and the SAI model was used for the benzene storage and benzene fugitive plants. However, the ISC model was used for a few plants with benzene storage and fugitive emissions to compare the results of that model with the SAI model. For plants containing multiple sources, the same meteorological and population data were used for each plant each time the risks were calculated for one of the sources in that plant.

APPENDIX A – EMISSIONS SOURCE TEST DATA AND ANALYSIS

This appendix provides a summary description of the emission tests conducted on internal floating roof (IFR) tanks and the major results. For additional and complete information, refer to the referenced reports.

A.1 TEST PROCEDURES

All emissions test measurements were obtained by Chicago Bridge and Iron Company (CBI) under contract to the American Petroleum Institute.[1] The test program was divided into two broad components: pilot tank test measurements and internal floating roof tank component measurements. The primary goal of the pilot tank tests was to determine emissions from IFR seal systems and deck seams; while the purpose of the IFR component tests was to determine emissions from IFR fittings (hatches, ladder wells, etc.) and to investigate other issues such as the permeability of seal systems to the stored hydrocarbon.

A.1.1 Pilot Test Tank Emission Measurements

A.1.1.2 Description of Test Facility. The tests were performed in a test IFR tank at CBI's research facility in Plainfield, Illinois. The test tank was 20 feet in diameter and had a 9-foot shell height (see Figure A-1). The lower 5'3" of the tank shell was provided with a heating/cooling jacket through which a heated or cooled water/ethylene glycol mixture was continuously circulated to control the product temperature. The effect of air blowing through the shell vents was simulated by means of a blower connected to the tank by a 12-inch diameter duct. This air exited from the tank through a similar duct.

Based on wind tunnel tests, it has been possible to determine the pressure coefficient, C_p, variation over the exterior surface of the tank. The air flow rate through the vents over the internal floating roof was then related to C_p by means of a mathematical model.[1] Thus,

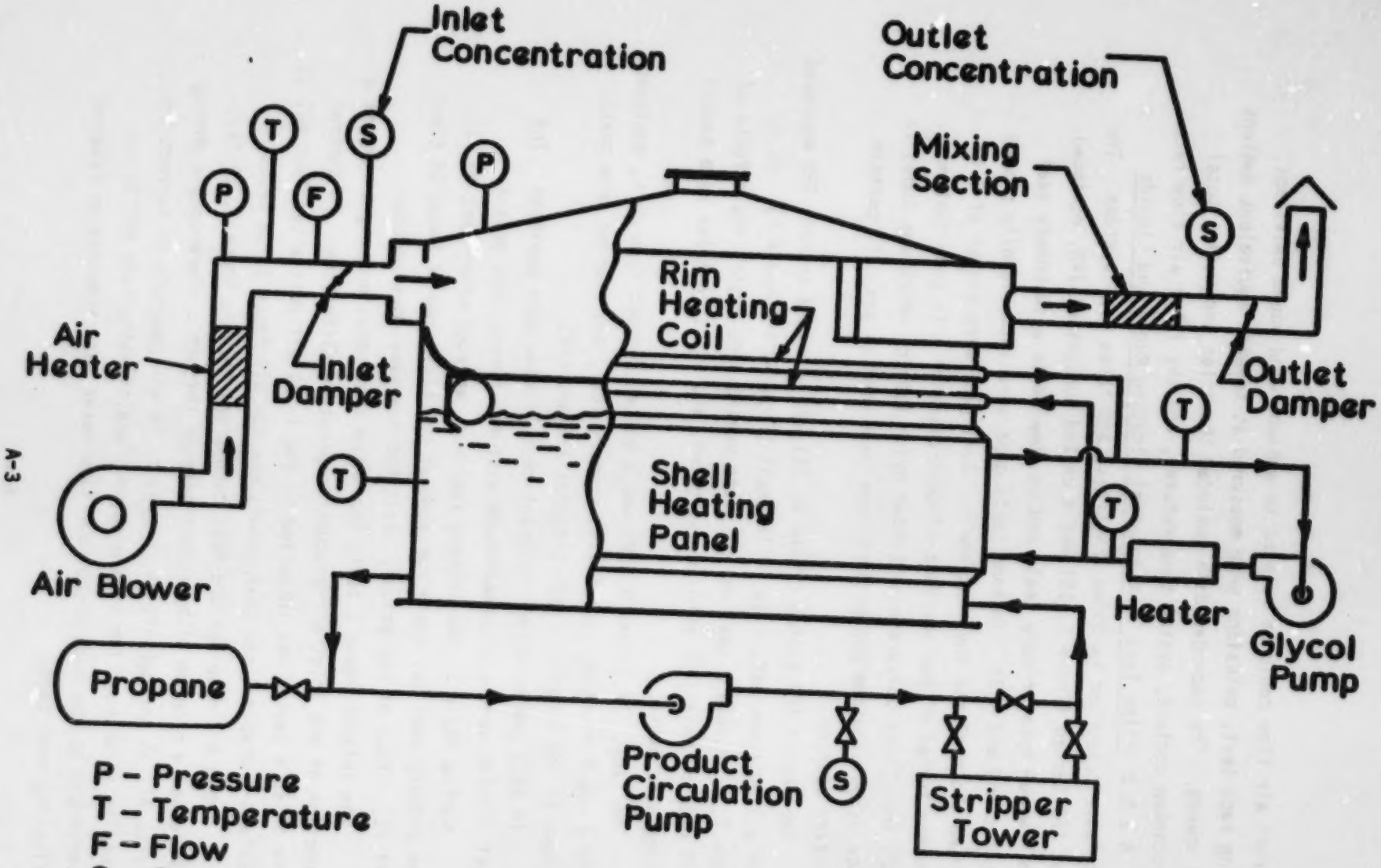

Figure A-1. Process and instrumentation schematic.[1]

internal air flow could be related to ambient wind speed emissions. During each test, emissions were measured at several equivalent ambient wind speeds. The recorded data included the inlet and outlet total hydrocarbon content, system temperatures, and the inlet air flow rate.

A.1.1.3 Pilot Test Tank Internal Floating Roofs and Liquids. Tests were conducted in three IFR types, and three seal systems. The first IFR tested (Phase 1, 1R) was a bolted noncontact IFR, equipped with a wiper type primary seal, and on some tests a secondary seal (Figures A-2 and A-3). In some tests gaps were intentionally placed between the seal and the tank shell. Seal gaps were either of 1 or 3 square inches of gap per-foot-of-tank-diameter. In some instances, 0.020 inch thick polyurethane-coated nylon fabric, which was taped in place using aluminum-backed duct tape, was used to seal off certain emission sources.

The second IFR tested (Phase 2, 2R) was a welded contact IFR equipped with a liquid-mounted, foam filled seal (Figures A-4 and A-5). As in Phase 1, a secondary seal was in place during some tests; the effects of seal gaps on emissions were investigated; and emission areas were sealed during some tests.

The final IFR (Phase 3, 3R) was a bolted contact type deck, equipped with a vapor-mounted, foam-filled primary seal, and (during some tests) a foam-filled secondary seal (Figures A-6 and A-7).

In each phase, three different test liquids were employed. The test liquids were a propane/octane mixture, hexane, and octane.

During Phase 1, the primary seal was replaced after Test No. 13. The primary seal was again replaced at the beginning of Phase 1R (Test API 73). Each of the primary seals had the same construction.

The initial Phase 1 tests indicated that emissions might vary as a function of the inlet air-product temperature difference. To control for this, a heater was installed in the inlet air duct after Test API 19. Table A-1 displays the test conditions for all Phase 1, 1R tests.

Table A-2 displays the test conditions for the Phase 2, 2R tests. There was a problem with product seepage through a thermocouple during Tests API 35 through API 44. However, it was possible to correct the results to account for this problem. Additionally Test API 51 was performed at the much higher air flow rates that simulate an external floating roof tank.

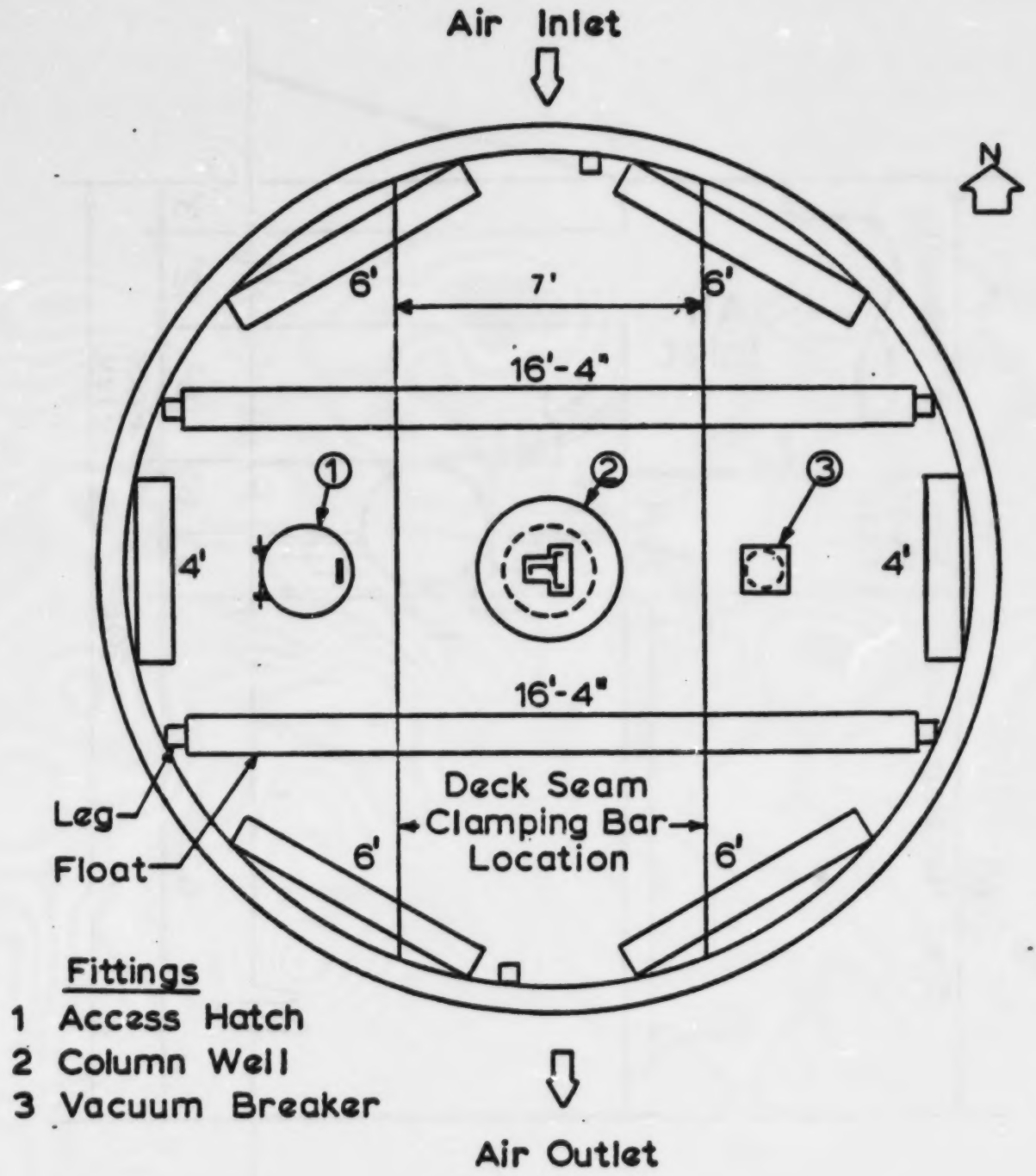

Figure A-2. Plan view of noncontact bolted IFR.[1]

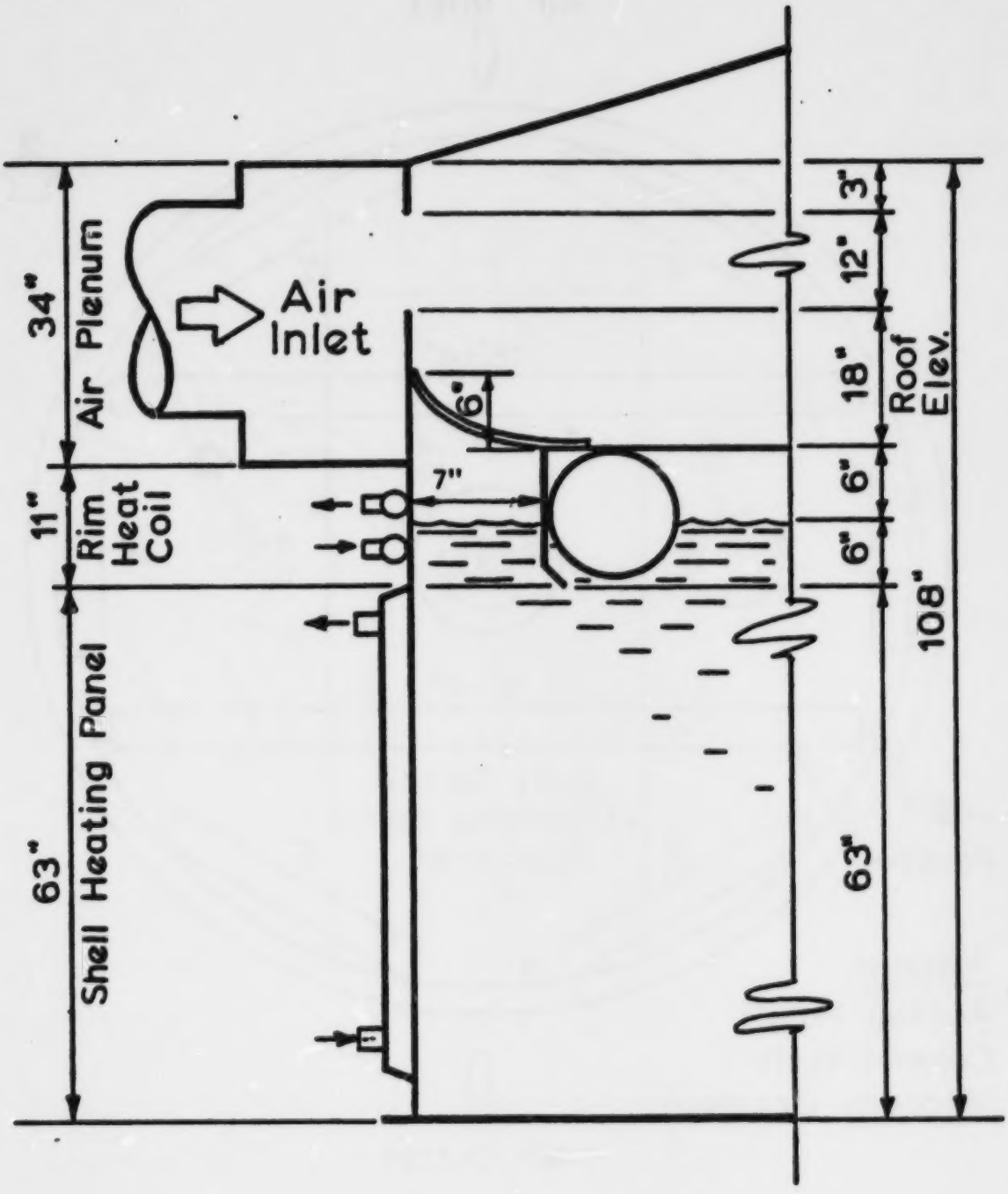

Figure A-3. Elevation view of noncontact bolted IFR in test tank.[1]

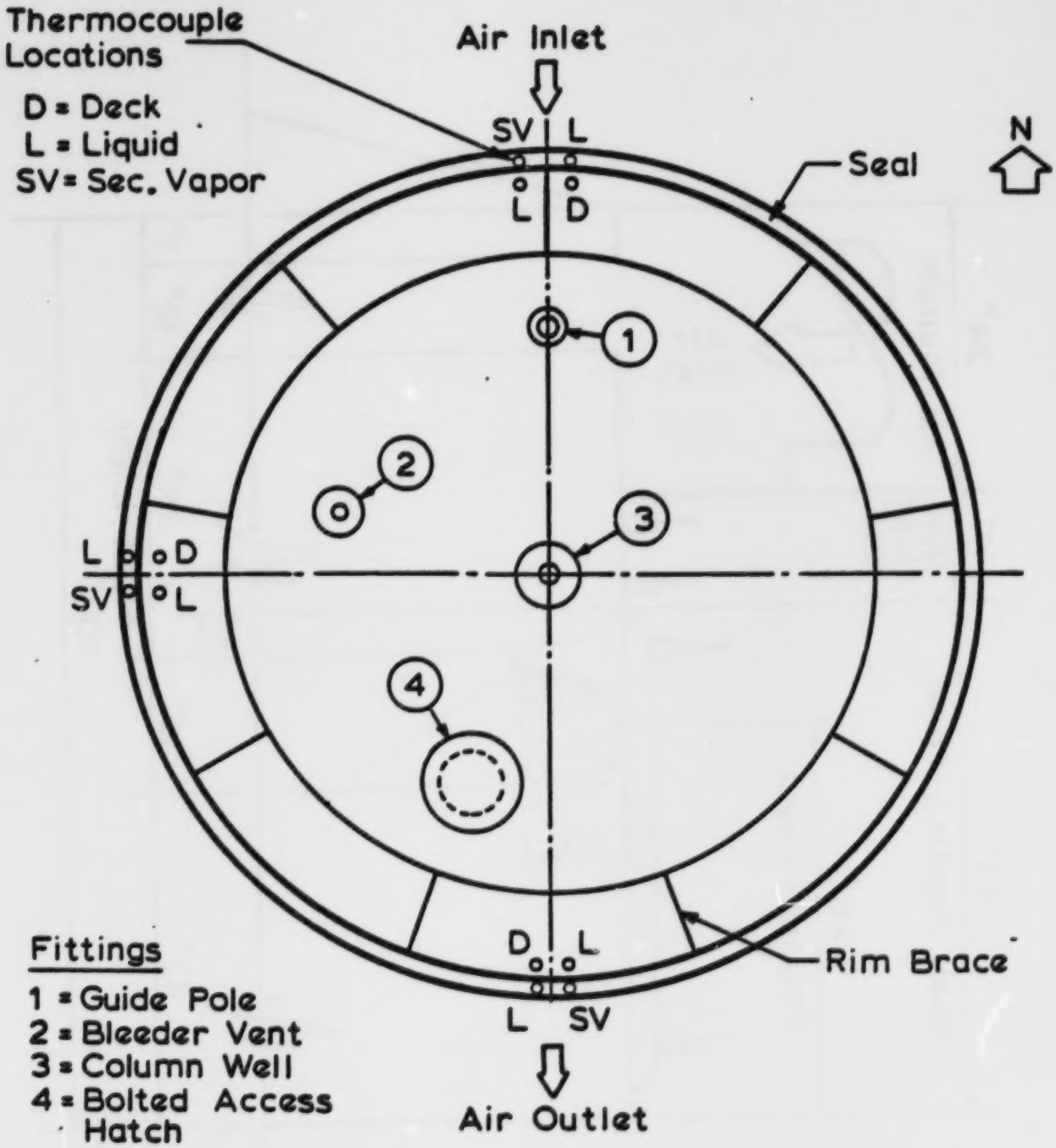

Figure A-4. Plan view of contact welded IFR.[1]

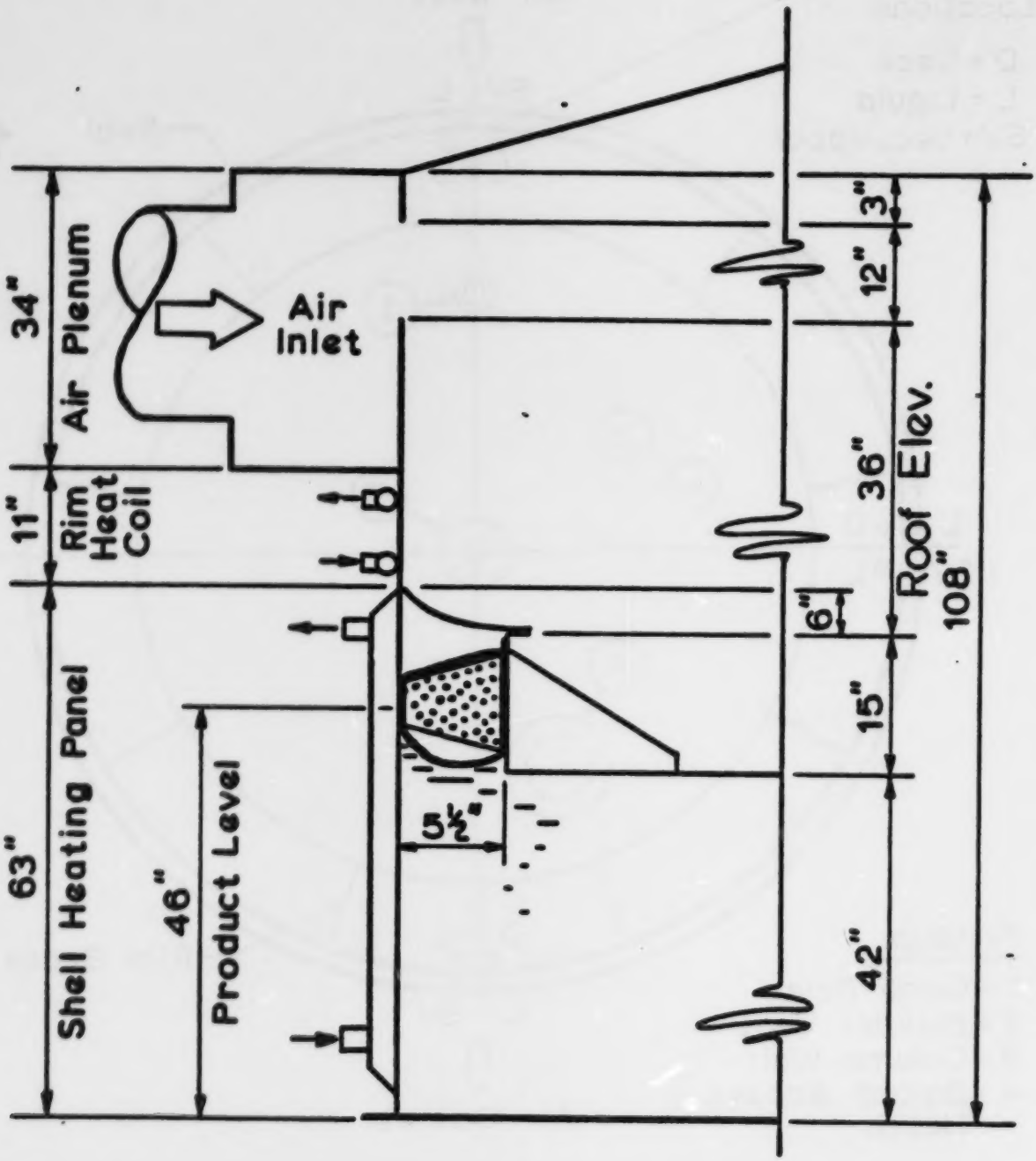

Figure A-5. Elevation view of contact welded IFR in test tank.[1]

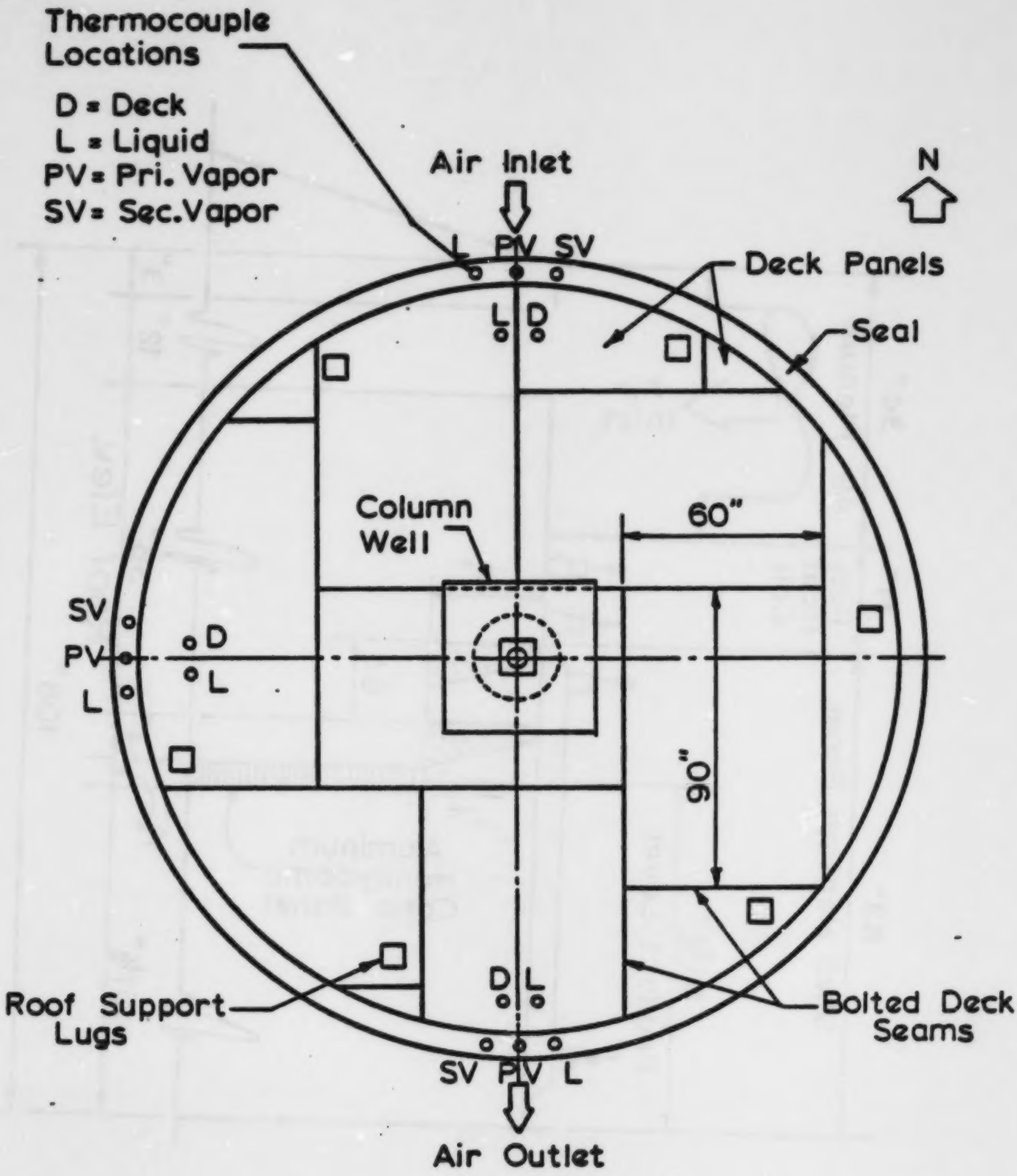

Figure A-6. Plan view of contact bolted IFR.[1]

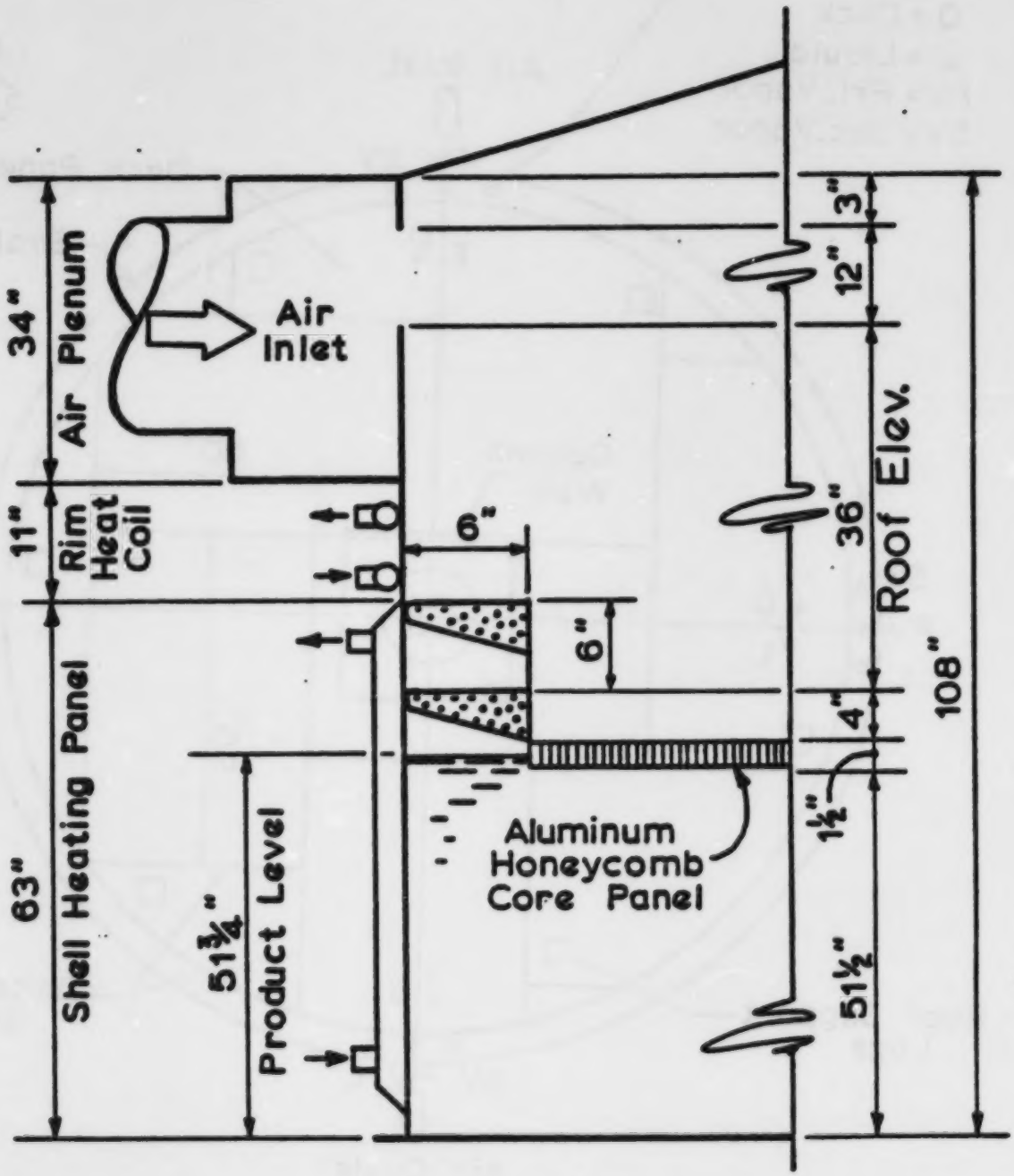

Figure A-7. Elevation view of contact bolted IFR in test tank.[1]

Table A-1. SUMMARY OF TEST CONDITIONS FOR PHASE 1 AND 1R

Test number	Product type	Nominal vapor pressure (psia)	Gap area (in^2/ft diameter)		Roof components			Nominal (air-product) temperature difference (°F)	Notes
			Primary	Secondary	Column wall	Deck fittings	Deck seams		
Phase 1:									
API 1	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 2	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 3	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 4	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	Air product
API 5	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	temperature
API 6	C3/nC8	5.0	0	—	Sealed	Sealed	Unsealed	Variable	difference
API 7	C3/nC8	5.0	1	—	Sealed	Sealed	Unsealed	Variable	was
API 8	C3/nC8	5.0	3	—	Sealed	Sealed	Unsealed	Variable	uncontrolled
API 9	C3/nC8	0.5	3	—	Sealed	Sealed	Unsealed	Variable	
API 10	C3/nC8	0.5	1	—	Sealed	Sealed	Unsealed	Variable	
API 11	C3/nC8	0.5	0	—	Sealed	Sealed	Unsealed	Variable	
API 12	C3/nC8	0.5	0 (1)	—	Sealed	Sealed	Unsealed	Variable	
New Primary Seal Installed									
API 13	nC8	0.5	0	—	Sealed	Sealed	Unsealed	Variable	
API 14	nC8	0.5	1	—	Sealed	Sealed	Unsealed	Variable	
API 15	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	Air product
API 16	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	temperature
API 17	C3/nC8	5.0	0	0	Sealed	Sealed	Unsealed	Variable	difference
API 18	C3/nC8	5.0	3	0	Sealed	Sealed	Unsealed	Variable	was
API 19	C3/nC8	5.0	3	1	Sealed	Sealed	Unsealed	Variable	uncontrolled
API 19A	C3/nC8	5.0	3	1 (2)	Sealed	Sealed	Unsealed	Variable	
Air Duct Heater Installed									
API 20	C3/nC8	Variable	0	—	Unsealed	Unsealed	Unsealed	0	(3)
API 21A	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	-15	
API 21B	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	0	
API 21C	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	+15	
API 21D	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	0	(4)
API 21E	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	Variable	
API 22A	C3/nC8	5.0	1	—	Unsealed	Unsealed	Unsealed	-15	
API 22B	C3/nC8	5.0	1	—	Unsealed	Unsealed	Unsealed	0	
API 22C	C3/nC8	5.0	1	—	Unsealed	Unsealed	Unsealed	+15	
API 22D	C3/nC8	5.0	1	—	Unsealed	Unsealed	Unsealed	Variable	
API 23	C3/nC8	5.0	Sealed	—	Sealed	Sealed	Unsealed	0	
API 24	C3/nC8	5.0	Sealed	—	Unsealed	Sealed	Unsealed	0	
API 25	C3/nC8	5.0	Sealed	—	Unsealed	Unsealed	Unsealed	0	

(continued)

Table A-1. Concluded

Test number	Product type	Nominal vapor pressure (psia)	Gap area (in^2/ft diameter)		Roof components			Nominal (air-product) temperature difference (°F)	Notes
			Primary	Secondary	Column well	Deck fittings	Deck seams		
API 26A	C3/nC8	3.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 26B	C3/nC8	2.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 27A	C3/nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	-15	
API 27B	C3/nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 27C	C3/nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	+15	
API 28	C3/nC8	0.5	0	—	Unsealed	Unsealed	Unsealed	0	
API 29	nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	0	(5)
API 29R	nC8	0.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 30	nC8	0.5	0	—	Unsealed	Unsealed	Unsealed	0	(5)
API 30R	nC8	0.5	0	—	Unsealed	Unsealed	Unsealed	0	
API 31	nC8	0.5	1	0	Unsealed	Unsealed	Unsealed	0	
API 31A	nC8	0.5	1	0	Unsealed	Unsealed	Unsealed	+15	
API 32	nC6	2.5	0	—	Unsealed	Unsealed	Unsealed	0	
API 33	nC6	2.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 33A	nC6	2.5	1	—	Unsealed	Unsealed	Unsealed	+15	
API 34	nC6	2.5	1	—	Unsealed	Unsealed	Unsealed	0	
API 34A	nC6	2.5	1	—	Unsealed	Unsealed	Unsealed	+15	
Phase 1R:									
API 73	C3/nC8	5.0	0	—	Unsealed	Unsealed	Unsealed	0	(7)
API 73A	C3/nC8	5.0	0	—	Unsealed(6)	Unsealed	Unsealed	0	
API 74	C3/nC8	5.0	0	—	Unsealed(6)	Unsealed	Unsealed	0	
API 75	C3/nC8	5.0	3	—	Unsealed(6)	Unsealed	Unsealed	0	
API 76	C3/nC8	5.0	Sealed	—	Sealed	Sealed	Unsealed	0	
API 76R	C3/nC8	5.0	Sealed	—	Sealed	Sealed	Unsealed	0	
API 77	C3/nC8	5.0	Sealed	—	Sealed	Sealed	Sealed	0	

Notes: (1). Seal closure devices were installed to eliminate all unintentional gaps.
(2). Gaps in the secondary seal were rotated 45° to position them directly above the primary seal gaps.
(3). Emission test data is questionable due to variable product temperature causing nonequilibrium conditions.
(4). Emission test data is questionable due to nonequilibrium condition in the rim vapor space due to prior air purge.
(5). Emission test data is questionable due to air inlet heater control problems.
(6). A column well gasket was used during this test.
(7). Emission test data is questionable due to nonequilibrium condition of product caused by insufficient mixing.

Table A-2. SUMMARY OF TEST CONDITIONS FOR PHASE 2 AND 2R (1)

Test number	Product type	Nominal vapor pressure (psia)	Gap area (in^2/ft diameter)		Roof components		Notes
			Primary	Secondary	Column well	Deck fittings	
Phase 2							
API 35	C3/nC8	5.0	0	-	Unsealed	Unsealed	(2)
API 36	C3/nC8	5.0	1	-	Unsealed	Unsealed	(2)
API 37	C3/nC8	5.0	0	-	Unsealed	Unsealed	(2)
API 38	C3/nC8	5.0	0.5	-	Unsealed	Unsealed	(2)
API 39	C3/nC8	5.0	3	-	Unsealed	Unsealed	(2)
API 40	C3/nC8	5.0	1	-	Unsealed	Unsealed	(2)
API 41	C3/nC8	5.0	0	0	Sealed	Sealed	(2)
API 42	C3/nC8	5.0	1	0	Sealed	Sealed	(2)
API 43	C3/nC8	5.0	3	1	Sealed	Sealed	(2)
API 44	C3/nC8	5.0	Sealed	-	Sealed	Sealed	(2)
Repaired Product Seepage Through Thermocouple Fitting							
API 45	C3/nC8	5.0	Sealed	-	Sealed	Sealed	
API 46	C3/nC8	5.0	Sealed	-	Unsealed	Sealed	
API 47	C3/nC8	5.0	Sealed	-	Unsealed	Unsealed	
API 48	C3/nC8	5.0	0	-	Unsealed	Unsealed	
API 49	C3/nC8	5.0	0	-	Sealed	Sealed	
API 50	nC8	0.5	1	-	Unsealed	Unsealed	(3)
API 51	nC8	0.5	1	-	Unsealed	Unsealed	(3), (4)
Phase 2R							
API 67A	nC8	0.5	1	-	Unsealed	Unsealed	(3)
API 67	nC8	0.5	1	-	Unsealed	Unsealed	
API 68	nC6	2.5	1	-	Unsealed	Unsealed	
API 69	nC6	2.5	1	0	Unsealed	Unsealed	
API 70	C3/nC8	5.0	1	0	Unsealed	Unsealed	
API 71	C3/nC8	5.0	1	-	Unsealed	Unsealed	
API 71A	C3/nC8	5.0	1	-	Unsealed	Unsealed	(5)
API 72	C3/nC8	2.5	1	-	Unsealed	Unsealed	

Notes: (1). During both Phases 2 and 2R, nominal (air-product) temperature difference was kept at zero.
(2). Product seepage through a thermocouple fitting occurred during this test.
(3). Product contained trace amount of propane.
(4). During this test the air flow rate was increased to simulate an external floating roof.
(5). During this test the inlet air and product heaters were turned off, and the wind speed was kept constant at about 10 mi/hr.

Table A-3 displays the test conditions of Phase 3 and 3R. During some tests product penetrated the primary seal. The problem was repaired, and the tests were repeated.

Table A-4 presents the results of all relevant tests. In summary, it was found that an air product temperature differential of up to 15F° had no significant effect on emissions. Small gaps (1 inch^2/feet diameter) did not appear to affect emissions significantly. Also, the tests demonstrate that ambient wind (particularly at speeds less than 20 miles per hour) has little or no effect on emissions.

A.1.1.4 IFR Component Tests.

A.1.1.4.1 Deck fitting emission tests. To quantify emissions from various types of fittings, a series of bench scale tests were performed. These fittings were placed through the top cover of a liquid-filled drum, and the drum was then placed on a scale. The weight change and other data were recorded over a 30 day period. Figure A-8 displays a sample bench test, and Table A-5 summarizes the results.

A.1.1.4.2 Permeability tests. A series of bench permeability tests were performed to determine the permeability of the 0.020 inch-thick polyurethane-coated nylon fabric to various hydrocarbon liquids. One laboratory test was also performed. Also included was a test on the same fabric of 0.037 inch thickness with benzene as a test liquid. This material had been used as the seal envelop material in Phase 2 and 2R, and in earlier test work.[2] The results are shown in Table A-6.

A.2 MAJOR RESULTS

This section discusses the major results of the analysis of test work. Although the relationship of emission factors to the test results is discussed, the actual development of emission factors is presented elsewhere.[3]

A.2.1 Seal Losses

Total measured emissions in a given tank test are the sum of all of the emission sources in that test. Therefore, to develop an emission factor the results must be reduced. For example, the permeation emissions through any sealing material, fittings, and any other source that is not of interest must be accounted for, and subtracted out before the emissions from the component of interest are known. Because of this reduction process, component emissions factors cannot be read directly from Table A-4.

Table A-3. SUMMARY OF TEST CONDITIONS FOR PHASE 3 AND 3R (1)

Test number	Product type	Nominal vapor pressure (psia)	Gap area (in²/ft diameter)		Roof components			Notes
			Primary	Secondary	Column well	Deck seams	Rim plate	
Phase 3								
API 52A	C3/nC8	5.0 -	0	0	Unsealed	Unsealed	Unsealed	(2)
API 52B	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2)
API 52C	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2)
API 52D	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2)
API 52E	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	(2), (3)
API 53A	C3/nC8	5.0	1	0	Unsealed	Unsealed	Unsealed	(2)
API 53B	C3/nC8	5.0	1	0	Unsealed	Unsealed	Unsealed	(2)
API 53C	C3/nC8	5.0	1	0	Unsealed	Unsealed	Unsealed	(2)
API 54A	C3/nC8	5.0	3	1	Unsealed	Unsealed	Unsealed	(2)
API 54B	C3/nC8	5.0	3	1	Unsealed	Unsealed	Unsealed	(2)
Product Liquid Removed From Primary Seal								
API 52	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	
API 52R	C3/nC8	5.0	0	0	Unsealed	Unsealed	Unsealed	
API 53	C3/nC8	5.0	1	0	Unsealed	Unsealed	Unsealed	
API 54	C3/nC8	5.0	3	1	Unsealed	Unsealed	Unsealed	
API 55A	C3/nC8	5.0	Sealed	Sealed	Sealed	Sealed	Sealed	
API 55	C3/nC8	5.0	Sealed	Sealed	Sealed	Sealed	Sealed	(4)
API 56	C3/nC8	5.0	Sealed	Sealed	Sealed	Unsealed	Sealed	(4)
API 57	C3/nC8	5.0	Sealed	Sealed	Sealed	Unsealed	Unsealed	(4)
API 58	C3/nC8	5.0	Sealed	Sealed	Unsealed	Unsealed	Unsealed	(4)
API 59	C3/nC8	5.0	0	-	Unsealed	Unsealed	Unsealed	
API 60	C3/nC8	5.0	1	-	Unsealed	Unsealed	Unsealed	
API 61	C3/nC8	5.0	3	-	Unsealed	Unsealed	Unsealed	
API 62	C3/nC8	2.5	1	-	Unsealed	Unsealed	Unsealed	
API 63	C3/nC8	0.5	1	-	Unsealed	Unsealed	Unsealed	
API 64	nC8	0.5	1	-	Unsealed	Unsealed	Unsealed	
API 65	nC6	2.5	1	-	Unsealed	Unsealed	Unsealed	
Phase 3R								
API 65R	nC6	2.5	1	-	Unsealed	Unsealed	Unsealed	
API 65A	nC6	2.5	1	-	Unsealed	Unsealed	Unsealed	(5)
API 66	nC6	2.5	1	0	Unsealed	Unsealed	Unsealed	(2)
API 66R	nC6	2.5	1	0	Unsealed	Unsealed	Unsealed	

Notes: (1). During both Phases 3 and 3R, Type 1 air flow distribution was used, the nominal (air-product) temperature difference was kept at zero, and the roof elevation was kept at 63 inches below the air inlet.
(2). Emission test data is of questionable value since liquid product was present in the primary seal.
(3). Column well cover intentionally positioned off center with a gap.
(4). All taped joints were also caulked during this test.
(5). During this test the primary seal gap plates were intentionally extended down into the product.

Table A-4. SUMMARY OF TEST RESULTS FOR ALL POTENTIALLY RELEVANT TESTS

CBI test number	Nominal true vapor pressure[1] (psia)	Average emissions lb-mole/day
API-1	5.00	0.283
API-2	5.00	0.423
API-3	5.00	0.309
API-4	5.00	0.449
API-5	5.00	1.33
API-7	5.00	0.224
API-8	5.00	0.439
API-12	0.50	0.0181
API-13	0.50	0.0605
API-14	0.50	0.0668
API-13R	0.50	0.0567
API-13, 13R	0.50	0.059
API-14R	0.50	0.196
API-14, 14R	0.50	0.159
API-16	5.00	0.926
API-17	5.00	0.0698
API-18	5.00	0.110
API-19	5.00	0.134
API-19A	5.00	0.147
API-21A	5.00	0.101
API-21B	5.00	0.0891
API-21C	5.00	0.0909
API-21AR	5.00	0.171
API-21A, AR	5.00	0.129
API-21BR	5.00	0.140
API-21B, BR	5.00	0.102
API-21CR	5.00	0.133
API-21C, CR	5.00	0.108
API-22A	5.00	0.142
API-22BI	5.00	0.165
API-22D	5.00	0.124
API-22B	5.00	0.176
API-22BI, B	5.00	0.173
API-22C	5.00	0.211
API-21E	5.00	0.128
API-23	5.00	0.0714
API-24	5.00	0.120
API-25	5.00	0.108
API-26A	5.00	0.117
API-26B	5.00	0.128
API-27A	0.50	0.030

(continued)

Table A-4. Continued

CBI test number	Nominal true vapor pressure[1] (psia)	Average emissions lb-mole/day
API-27B	0.50	0.0196
API-27C	0.50	0.0553
API-28	0.50	0.0167
API-30	0.50	0.0316
API-29R	0.50	0.143
API-31	0.50	0.0357
API-31A	0.50	0.0256
API-32	2.50	0.0232
API-33	2.50	0.0306
API-33A	2.50	0.0251
API-34	2.50	0.0317
API-34A	2.50	0.0347
API-35	5.00	0.0366
API-36	5.00	0.0359
API-37	5.00	0.0297
API-38	5.00	0.0334
API-39	5.00	0.0492
API-39R	5.00	0.0387
API-40	5.00	0.0301
API-41	5.00	0.0154
API-42	5.00	0.0176
API-43	5.00	0.0269
API-44	5.00	0.0149
API-45	5.00	0.00693
API-46	5.00	0.00928
API-47	5.00	0.0170
API-48	5.00	0.0246
API-49	5.00	0.0188
API-50	0.50	0.00426
API-51	0.50	0.0390
API-52	5.00	0.0376
API-53P	5.00	0.0407
API-54	5.00	0.0400
API-53	5.00	0.0372
API-53P, 53	5.00	0.0399
API-55	5.00	0.0156
API-56	5.00	0.0338
API-57	5.00	0.0345
API-58	5.00	0.0433
API-52R	5.00	0.0435
API-52, 52R	5.00	0.0400
API-59	5.00	0.0536

(continued)

Table A-4. Concluded

CBI test number	Nominal true vapor pressure[1] (psia)	Average emissions lb-mole/day
API-60	5.00	0.0574
API-61	5.00	0.0690
API-62	5.00	0.0649
API-63R	0.50	0.00930
API-64	0.50	0.00867
API-65	2.50	0.0242
API-66	2.50	0.0378
API-66R	2.50	0.0322
API-65R	2.50	0.0407
API-65A	2.50	0.0417
API-67A	0.50	0.00779
API-67	0.50	0.00500
API-68	2.50	0.0105
API-69	2.50	0.00715
API-70	5.00	0.0202
API-71	5.00	0.0247
API-72	5.00	0.040
API-73	5.00	0.0466
API-73A	5.00	0.0628
API-74	5.00	0.0627
API-75	5.00	0.0730
API-76	5.00	0.0509
API-76R	5.00	0.0433
API-76, 76R	5.00	0.0484
API-77	5.00	0.0417

[1]Nominal average true vapor pressure (TVP) is the TVP at which the emissions were calculated by using the vapor pressure function to normalize the measured hydrocarbon concentration to the concentration expected at the nominal TVP.

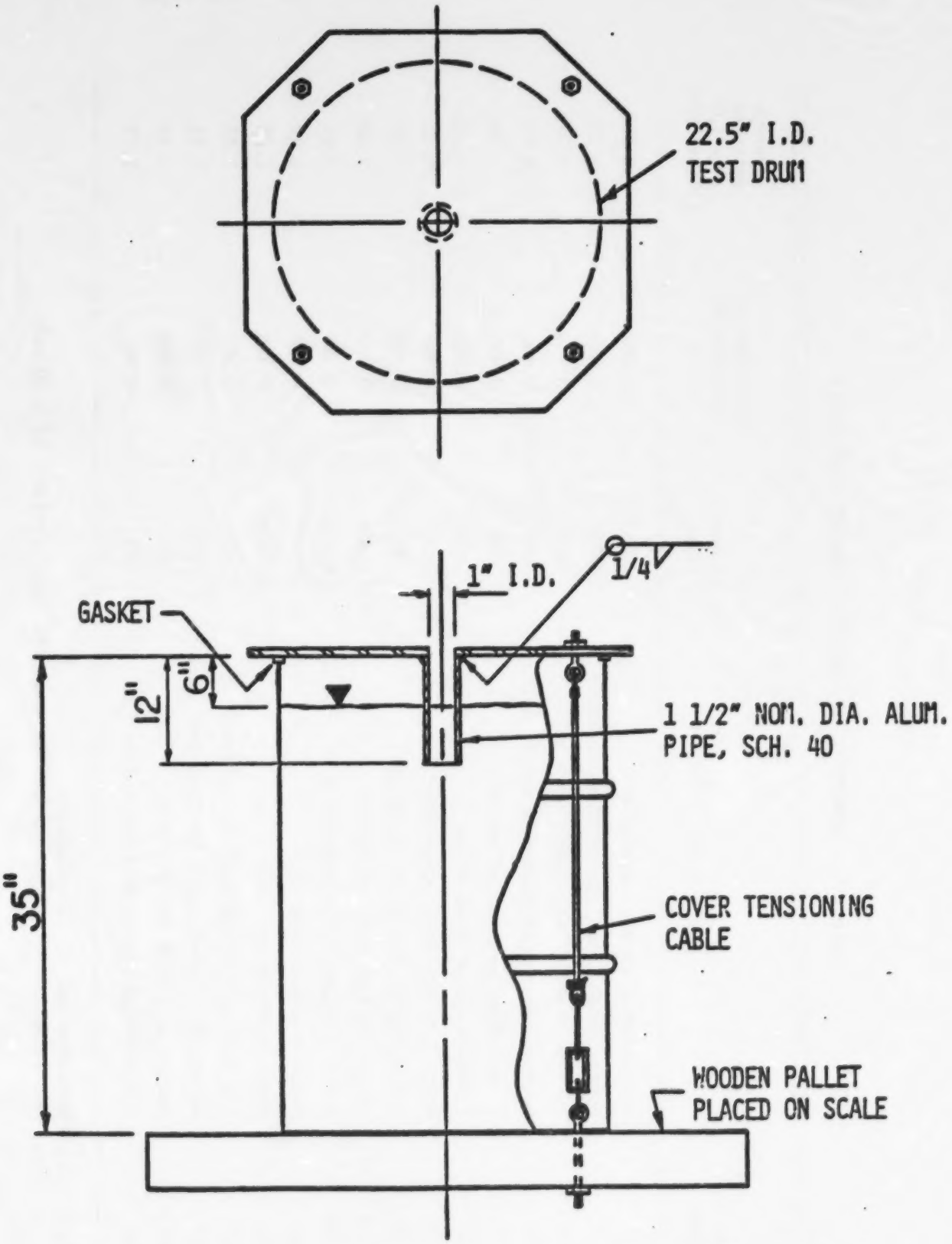

Figure A-8. Example of fitting emission bench test apparatus.[1]

Table A-5. SUMMARY OF IFR DECK FITTING EMISSION TESTS

Test number	Description	Product type	Correlation coefficient (-)	Average emission rate (2) (lb mole/yr)
1	Access hatch cover, ungasketed	nC6	0.681	0.204
2	Access hatch cover, gasketed and clamped	nC6	0.689	0.158
3	1½ inch diameter adjustable roof leg	nC6	0.914	0.977
4	8 inch diameter slotted pipe sample well	nC6	0.996	4.69
5	8 inch diameter pipe column well	nC6	0.989	2.11
6	1 inch diameter stub drain	nC6	0.902	0.279
7	Phase 1 column well, ungasketed	nC6	0.998	4.32
8	½ inch gap around built-up column	nC6	0.998	5.42
9A	Phase 1 column well, gasketed	C3/nC8	0.977	3.38
9B	Phase 1 column well, ungasketed	C3/nC8	0.959	5.07
10	Phase 2 column well	C3/nC8	0.964	1.22
11	Phase 3 column well (1)	C3/nC8	0.986	2.25
12	1/8 inch gap around built-up column	nC6	0.983	2.44
13	Access hatch cover with 1/8 inch gap	nC6	0.997	5.61
14	Sample well with 10% gap area	nC6	0.985	1.45
15	1/8 inch gap around built-up column (1)	nC6	0.983	2.81

Notes: (1). Test drum was 30 in. diameter.
(2). Average emission rate normalized to a nominal vapor pressure of 5.00 psia.

Table A-6. PERMEABILITY OF POLYURETHANE COATED NYLON FABRIC

Test number	Fabric thickness (in)	Fabric area (ft^2)	Length of taped seams (in)	Product type	Average product temperature (°F)	Average vapor pressure (psia)	Vapor mole weight (lbm/lbmole)	Average emission rate (lbm/day)	Correlation coefficient (-)	Average rate (lbm/ft^2 day)	Notes
16	0.020	2.75	--	C3/nC8	59.2	7.13	45.8	0.0612	0.838	0.0222	
17	0.037	2.75	--	C6H6	60.5	1.22	78.1	0.159	0.996	0.0578	
18	0.037	2.75	--	nC6	60.1	1.98	86.2	0.0158	0.663	0.00578	
19	0.020	2.75	--	C3/nC8	53.8	3.86	46.6	0.0652	0.783	0.0237	
20	0.020	2.75	--	C3/nC8	48.1	3.56	46.3	0.0808	0.806	0.0294	
21	0.020	2.75	48	C3/nC8	50.9	4.68	45.9	0.0650	0.863	0.0236	(1)
22	0.020	2.75	--	C3/nC8	43.2	3.59	46.0	0.0344	0.805	0.0125	
23	1/16" thk aluminum		60	C3/nC8	44.2	3.38	46.3	0.00273	0.096	--	(1)
Laboratory Permeability Test											
--	0.020	0.467	--	nC6	74.8	1.85	86.2	0.0244	--	0.0522	

Notes: (1). Aluminum backed duct tape was used on all taped seams.

For seal systems, it was found that

$$E_s = K_r \, Mw \, D \, P^* \qquad (C\text{-}1)$$

Where:

E_s = Emissions from the seal area in lbs/day

K_r = Seal factor

Mw = Molecular weight of vapor

D = Tank diameter

P* = Vapor pressure function

The reduced emissions from seals of similar construction and gap condition are averaged together. A seal emission factor is the weighted average of the averaged reduced emissions. Weights are selected according to field survey data that relate seal gap area to frequency of occurrence. The emission factor which results from this procedure of repeated subtraction and averaging does not represent any given tank, but is rather an expected value.

The analysis shows that for emission purposes seals may be divided into two types: liquid-mounted and vapor-mounted. An emission comparison of reduced results between the foam-filled vapor-mounted seal tested during Phase 3 and 3R and the vapor-mounted wipers tested in Phase 1 and 1R, shows that emissions from the foam-filled seal were lower than the Phase 1 wiper but higher than the Phase 1R wiper (Table A-7). On this basis, the results from Phases 1, 1R, 3 and 3R were merged into the general category of vapor-mounted seal.

The analysis shows that emissions from the liquid-mounted seal tested in Phase 2 and 2R are lower than both the average of the merged vapor-mounted seal tests and the individual vapor-mounted seal systems that were actually tested (Table A-8).

Another finding was the presence of the secondary seal reduced emissions whether or not the primary seal was gapped. Emissions reductions obtained by a secondary seal average 47 percent for a liquid-mounted primary seal and 63 percent for a vapor-mounted primary seal.

A.2.2 Deck Seam Losses

The welded IFR tested in Phase 2 and 2R was assumed to have no deck seam emissions. The IFR's tested in Phases 1, 1R, 3 and 3R have bolted deck seams. The seams in the contact deck (3 and 3R) had a different construction than those in the noncontact deck (1 and 1R). However, the

Table A-7. COMPARISON OF WIPER SEALS TO FOAM-FILLED VAPOR-MOUNTED SEALS

Seal gaps (in^2/ft diameter)	Seal emissions (lb mole/day)		
	Phase 1 wiper	Foam-filled	Phase 1R wiper
0	0.0566	0.0248	0.0217
1	0.0978	0.0324	—[1]
3	—[1]	0.0402	0.0319

[1]No test available.

Table A-8. COMPARISON OF LIQUID-MOUNTED SEAL TO VAPOR-MOUNTED SEAL

Seal gap (in^2/ft diameter)	Seal emissions (lb mole/day)	
	Liquid-mounted	Vapor-mounted[1]
0	0.0052	0.0217
1	0.0176	—[2]
3	0.030	0.0319

[1]Based on the best performing vapor-mounted seal (Phase 1R wiper).

[2]No test available.

test data show that there is no significant difference in emissions from the seams in the two decks (on a per-foot-of-seam-basis) despite differences in construction and position relative to the stored liquid (Table A-9). It should be noted that Test API 76 was not used in making the comparison. API representatives have stated that due to slight problems in the test, Test API 76 is not comparable with API 76R.[4]

The per-foot-of-seam results that appear in Table A-9 were averaged together and divided by the value of the vapor pressure function to develop the deck seam emission factor K_d. Further minor mathematical procedures are needed to develop K_d as it appears in Chapter 3. These procedures relate seam length to deck diameter.

A.2.3 Effect of Liquid Type on Emissions

Comparisons between previous test programs had indicated that emissions for single component (pure) liquids (e.g., benzene), could be significantly higher than emissions from multicomponent liquids (e.g., gasoline) when normalized for both molecular weight and vapor pressure.[2] Tests performed in the API program show that between the tested liquids (hexane, propane/octane, and octane) there were no significant emissions differences after normalizing for molecular weight and vapor pressure (Table A-10).

A.2.4 The Effect of Vapor Pressure on Emissions

Several emissions tests (from Phase 2 and 2R) were conducted to determine the effect of the product vapor pressure, P, on the emissions rate. This relationship was evaluated during these tests by varying the product vapor pressure in the pilot test tank which had been fitted with a contact-type internal floating roof and a liquid-mounted primary seal. Based on these tests, the emissions are directly related to the vapor pressure function, P*:

$$P^* = \frac{\frac{P}{14.7}}{\left\{1 + \left\{1 - \frac{P}{14.7}\right\}^{0.5}\right\}^2}$$

A.2.5 Fitting Emissions

The fitting emission factors are developed by a procedure similar to that used for seal factors. A particular fitting design is analyzed to determine emission points and the results of the bench tests are

Table A-9. BOLTED DECK SEAM EMISSIONS[1]

Test number	Product type	Nominal vapor pressure (psia)	Vapor mole weight (lbm/lbmole)	Deck seams	Total deck seam length (ft)	Emissions at nominal vapor pressure (lbmole/day)	Emissions per foot of deck seam (lbmole/day)
Bolted, Contact IFR							
API 55	C3/nC8	5.00	48.1	Sealed	89	0.0156	0.0002
API 56	C3/nC8	5.00	48.2	Unsealed	89	0.0338	
Bolted, Noncontact IFR							
API 76R	C3/nC8	5.00	46.8	Unsealed	36	0.0433	0.00004
API 77	C3/nC8	5.00	47.1	Sealed	36	0.0417	

[1]Other test conditions:

Primary seal - sealed
Secondary seal - none
Deck fittings - sealed

Table A-10. COMPARISON OF EMISSIONS AS A FUNCTION OF LIQUID TYPE

Test number[1]	Product type	Emissions[2] (lb mole/day)
Phase 2, 2R		
API 50	nC8	0.0510
API 67	nC8	0.0599
API 67A	nC8	0.0932
API 68	nC6	0.0233
API 69	nC6	0.0159
API 71	C3/nC8	0.0247
API 72	C3/nC8	0.040
API 36	C3/nC8	0.0359
Phase 3, 3R		
API 64	nC8	0.103
API 65	nC6	0.0537
API 65R	nC6	0.0905
API 65A	nC6	0.0927
API 60	C3/nC8	0.0574

[1]All tests had identical conditions as follows:

a. 1 in^2/ft. diameter of gap on primary seal.
b. No secondary seal.
c. All roof components unsealed.

[2]Emissions are normalized to 5.0 psia.

added and subtracted to account for each emission source in the design. The individual emission sources are summed, and the resulting sum is made independent of molecular weight and vapor pressure to form the fitting factor.

The test results show that the addition of gaskets and the bolting of covers will reduce emissions from fittings. Also demonstrated is the fact that small fitting design differences can lead to significant differences in emissions.

A.3 REFERENCES

1. Laverman, Royce J. et. al. Testing Program to Measure Hydrocarbon Emissions from a Controlled Internal Floating Roof Tank; (Unpublished), Chicago Bridge and Iron Co. Chicago, Illinois. March 1982. 304 pp.

2. U.S. Environmental Protection Agency. Measurements of Benzene Emissions from a Floating Roof Test Tank. Report No. EPA-450/3-79-020. Research Triangle Park, N.C. June 1979.

3. Letter and attachments from O'Keefe, William, F., American Petroleum Institute, to Wyatt, Susan R., EPA. January 25, 1983.

4. Moody, W.T., TRW, Meeting on September 2, 1982, Durham, N.C., between API, EPA, and TRW.

APPENDIX B

METHODOLOGY FOR ESTIMATING LEUKEMIA INCIDENCE AND MAXIMUM LIFETIME RISK FROM EXPOSURE TO BENZENE STORAGE TANKS

B.1 INTRODUCTION

The purpose of this appendix is to describe the methodology and to provide the information used to estimate leukemia incidence and maximum lifetime risk from population exposure to benzene emissions from benzene storage tanks. The methodology consists of four major components: estimation of annual average concentration patterns of benzene in the region surrounding each plant, estimation of the population exposed to each computed concentration, calculation of exposure by summing the products of the concentrations and associated populations, and calculation of annual leukemia incidence and maximum lifetime risk from the concentration and exposure estimates and a health effects estimate represented by a unit risk factor. Due to the assumptions made in each of these four steps of the methodology, there is considerable uncertainty associated with the lifetime individual risk and leukemia incidence numbers calculated in this appendix. These uncertainties are explained in Section B.6 of this appendix.

B.2 ATMOSPHERIC DISPERSION MODELING AND PLANT EMISSION RATES

The Human Exposure Model (HEM) was used to estimate concentrations of benzene around approximately 126 plants that contain benzene storage tanks.[1] The HEM estimates the annual average ground-level concentrations resulting from emissions from point and area sources. For point sources, the dispersion model within HEM is a Gaussian model that uses the same basic dispersion algorithm as the climatological form of EPA's Climatological Dispersion Model.[2] Gaussian concentration files are used in conjunction with multi-year STAR data and annual emissions data to estimate annual average concentrations. Details on this aspect of the HEM can be found in Reference 1.

Seasonal or annual stability array (STAR) summaries are principal meteorological input to the HEM dispersion model. STAR data are standard climatological frequence-of-occurrence summaries formulated for use in EPA models and available for major U.S. sites from the National Climatic Center, Asheville, N.C. A STAR summary is a joint frequency of occurrence of wind speed stability and wind direction categories, classified according to the Pasquill stability categories. For this modeling analysis, annual STAR summaries were used.

The model receptor grid consists of 10 downwind distances located along 16 radials. The radials are separated by 22.5-degree intervals beginning with 0.0 degrees and proceeding clockwise to 337.5 degrees. The 10 downwind distances for each radial are 0.2, 0.3, 0.5, 0.7, 1.0, 2.0, 5.0, 10.0, 15.0, and 20.0 kilometers. The center of the receptor grid for each plant was assumed to be plant center as determined by review of maps.

Inputs to the dispersion model include the geographical coordinates for each plant, and the emission rates, dimensions and plume characteristics for each storage tank in each plant. The latitudes and longitude for each plant, used in selecting the STAR site, are listed in Table B-1. Four model units representing the different types of plants that would have benzene storage tanks were developed: large producers of benzene, small producers of benzene, benzene consumers, and bulk storage terminals. The model units were assigned to each plant according to the uses of benzene within the plant. Where a plant had two model units assigned to it (e.g., a plant may be both a producer and consumer of benzene), emissions from both model units were used in calculating the concentration pattern around the plant. The model units assigned to each plant are listed in Table B-1.

Each model unit consists of a set of benzene storage tanks with specified dimensions, roof types, turnovers, and emission rates. The tank parameters used in the dispersion model are the same for benzene consumers and bulk storage terminals; therefore, no differentiation was made between them for modeling purposes. Table B-2 shows, for each model unit, the height and vertical cross-sectional area (used in downwash calculations) of each tank. The table also shows the emissions from

Table B-1. PLANTS AND LOCATIONS FOR BENZENE STORAGE TANKS

Plant	Location	Coordinates		Model Plant Type[a]
		Longitude	Latitude	
Region II				
1. American Cyanamid	Boundbrook, NJ	74°06'04"	40°33'25"	C/T
2. DuPont	Gibbstown, NJ	75°17'50"	39°50'25"	C/T
3. Exxon	Linden, NJ	74°12'49"	40°38'10"	SP,C/T
4. Standard Chlorine	Kearny, NJ	74°06'39"	40°45'03"	C/T
5. Texaco	Westville, NJ	75°08'42"	39°52'05"	LP,C/T
6. Ashland Oil	North Tonawanda, NY	78°55'27"	42°59'45"	SP
7. ICC Industries	Niagara Falls, NY	79°00'55"	43°03'33"	C/T
8. Commonwealth Oil	Penuelas, PR	66°42'00"	18°04'00"	LP,C/T
9. Phillips Puerto Rico	Guyama, PR	66°07'00"	17°59'00"	LP,C/T
10. Puerto Rico Olefins	Penuelas, PR	66°42'00"	18°04'00"	C/T
11. Union Carbide	Penuelas, PR	66°42'00"	18°04'00"	C/T
12. Amerada Hess	St. Croix, VI	64°44'00"	17°45'00"	LP
Region III				
13. Getty	Delaware City, DE	75°37'45"	39°35'15"	SP
14. Standard Chlorine	Delaware City, DE	75°38'47"	39°33'54"	C/T
15. Sun-Olin	Claymont, DE	76°25'40"	39°48'20"	C/T
16. Continental Oil	Baltimore, MD	77°34'02"	39°14'19"	C/T
17. Atlantic Richfield	Beaver Valley, PA	80°21'20"	40°39'21"	C/T
18. Gordon Terminals	McKees, PA	80°03'10"	40°28'22"	C/T
19. Gulf Oil	Philadelphia, PA	75°12'31"	39°54'18"	LP,C/T
20. Standard Oil (Ohio)/BP Oil	Marcus Hook, PA	75°37'45"	39°35'15"	SP
21. Sun Oil	Marcus Hook, PA	75°24'51"	39°48'45"	SP
22. U.S. Steel	Neville Island, PA	80°05'00"	40°30'00"	C/T
23. Allied Chemical	Moundsville, WV	80°48'04"	39°55'00"	C/T
24. American Cyanamid	Willow Island, WV	81°19'08"	39°21'45"	C/T
25. Mobay Chemical	New Martinsville, WV	80°49'50"	39°43'30"	C/T
26. PPG	Natrium, WV	80°52'14"	39°44'46"	C/T
27. Union Carbide	Institute, WV	81°47'05"	38°22'40"	C/T

(continued)

Table B-1. Continued

Plant	Location	Coordinates		Model Plant Type[a]
		Longitude	Latitude	
Region IV				
28. Jim Walter Resources	Birmingham, AL	86°47'30"	33°35'30"	C/T
29. Reichhold Chemicals	Tuscaloosa, AL	87°28'21"	33°15'06"	C/T
30. Ashland Oil	Ashland, KY	82°36'32"	38°22'30"	LP
31. B.F. Goodrich	Calvert City, KY	88°19'51"	37°03'19"	C/T
32. GAF	Calvert City, KY	88°24'48"	37°02'51"	C/T
33. Olin Corporation	Brandenburg, KY	86°07'15"	38°00'30"	C/T
34. Chevron	Pascagoula, MS	88°28'37"	30°19'04"	SP
35. First Chemical	Pascagoula, MS	88°29'45"	30°20'57"	C/T
Region V				
36. Clark Oil	Blue Island, IL	87°42'07"	41°39'19"	C/T
37. Core-Lube	Danville, IL	87°32'30"	40°07'10"	C/T
38. Monsanto	Sauget, IL	90°10'11"	38°36'06"	C/T
39. National Distillers (U.S.I.)	Tuscola, IL	88°21'00"	39°47'53"	C/T
40. Northern Petrochemicals	Morris, IL	88°25'42"	41°21'28"	C/T
41. Shell Oil	Wood River, IL	90°04'24"	38°50'26"	LP
42. Union Oil (California)	Lemont, IL	88°00'10"	41°40'20"	SP
43. Dow Chemical	Bay City, MI	89°52'22"	43°37'21"	LP,C/T
44. Dow Chemical	Midland, MI	84°12'18"	43°35'42"	C/T
45. Sun Oil	Toledo, OH	83°31'40"	41°36'52"	LP
46. Vertac/Transvaal	Jacksonville, AR	92°04'56"	34°55'36"	C/T
47. Allied Chemical	Geismar, LA	91°03'12"	30°12'55"	C/T
48. American Hoechst	Baton Rouge, LA	91°12'40"	30°33'03"	C/T
49. Cities Service	Lake Charles, LA	93°19'01"	30°10'58"	SP
50. Continental Oil	Lake Charles, LA	93°16'35"	30°14'30"	C/T
51. Cos-Mar, Inc.	Carrville, LA	91°04'09"	30°14'10"	C/T
52. Dow Chemical	Plaquemine, LA	91°14'30"	30°19'50"	LP

(continued)

Table B-1. Continued

Plant	Location	Coordinates		Model Plant Type[a]
		Longitude	Latitude	
Region VI (continued)				
53. Exxon	Baton Rouge, LA	91°10'17"	30°29'14"	LP
54. Gulf Coast Olefins	Taft, LA	90°26'23"	29°59'16"	C/T
55. Gulf Oil	Alliance, LA	89°58'26"	29°41'00"	LP
56. Gulf Oil	Donaldsonville, LA	90°55'19"	30°05'44"	C/T
57. Pennzoil United (Atlas Processing)	Shreveport, LA	93°46'13"	32°28'12"	LP
58. Rubicon	Geismar, LA	91°00'37"	30°11'06"	C/T
59. Shell Oil	Norco, LA	90°27'35"	29°59'42"	C/T
60. Tenneco	Chalmette, LA	89°58'19"	29°55'56"	SP
61. Union Carbide	Taft, LA	90°27'15"	29°59'17"	LP
62. Sun Oil	Tulsa, OK	96°01'15"	36°08'25"	C/T,SP
63. Amerada Hess	Houston, TX	95°14'15"	29°41'39"	C/T
64. American Hoechst	Bayport, TX	95°01'15"	29°36'10"	C/T
65. American Petrofina of Texas	Port Arthur, TX	93°53'20"	29°57'30"	SP
66. American Petrofina (Cosden Oil)	Big Spring, TX	101°24'55"	32°16'11"	LP,C/T
67. American Petrofina/ Union Oil of California	Beaumont, TX	93°58'45"	30°00'00"	SP,C/T
68. Atlantic Richfield	Channelview, TX	95°07'30"	29°50'00"	LP
69. Atlantic Richfield (ARCO/Polymers)	Houston, TX	95°13'54"	29°43'10"	LP
70. Atlantic Richfield (ARCO/Polymers)	Port Arthur, TX	93°58'15"	29°51'24"	C/T
71. Celanese	Pampa, TX	100°57'47"	35°32'07"	C/T
72. Charter International	Houston, TX	95°15'09"	29°40'17"	SP
73. Coastal States Gas	Corpus Christi, TX	97°26'44"	27°48'42"	LP,C/T
74. Corpus Christi Petrochemicals	Corpus Christi, TX	97°31'21"	27°50'02"	SP,C/T
75. Cosden Oil	Groves, TX	93°52'58"	29°57'46"	C/T

(continued)

Table B-1. Continued

Plant	Location	Coordinates		Model Plant Type[a]
		Longitude	Latitude	
Region VI (continued)				
76. Crown Central	Pasadena, TX	95°10'30"	29°44'40"	SP
77. Dow Chemical(A)	Freeport, TX	95°19'55"	28°57'23"	LP,C/T
78. Dow Chemical(B)	Freeport, TX	95°24'09"	28°59'17"	LP,C/T
79. Dow Chemical	Orange, TX	93°45'14"	30°03'20"	C/T
80. DuPont	Beaumont, TX	94°01'40"	30°00'51"	C/T
81. DuPont	Orange, TX	93°44'44"	30°03'24"	C/T
82. Eastman Kodak	Longview, TX	94°41'24"	32°26'17"	C/T
83. El Paso Natural Gas	Odessa, TX	102°19'29"	31°49'27"	C/T
84. El Paso Products/ (Rexene Polyolefins)	Odessa, TX	102°20'00"	31°49'22"	C/T
85. Exxon	Baytown, TX	95°01'04"	29°44'50"	LP,C/T
86. GATX Terminal Group	Houston, TX	95°13'29"	29°43'17"	C/T
87. Georgia-Pacific Corp.	Houston, TX	95°03'00"	29°37'20"	C/T
88. Goodyear Tire and Rubber	Bayport, TX	95°02'44"	29°39'43"	C/T
89. Gulf Oil Chemicals	Cedar Bayou, TX	94°55'10"	29°49'29"	C/T
90. Gulf Oil Chemicals	Port Arthur, TX	93°58'30"	29°51'30"	LP,C/T
91. Hercules	McGregor, TX	97°16'30"	31°30'15"	C/T
92. Howell	San Antonio, TX	98°27'36"	29°20'51"	SP
93. Independent Refining Corp.	Winnie, TX	94°20'28"	29°50'04"	SP
94. Kerr-McGee Corp. (Southwestern)	Corpus Christi, TX	97°25'24"	27°48'16"	SP
95. Marathon Oil	Texas City, TX	94°54'47"	29°22'21"	SP,C/T
96. Mobil Oil	Beaumont, TX	94°03'30"	30°04'00"	LP,C/T
97. Monsanto	Alvin (Chocolate Bayou)	95°12'44"	29°15'09"	LP,C/T
98. Monsanto	Texas City, TX	94°53'40"	29°22'44"	LP,C/T
99. Oxirane	Channelview, TX	95°06'29"	29°50'00"	C/T

(continued)

Table B-1. Continued

Plant	Location	Coordinates		Model Plant Type[a]
		Longitude	Latitude	
Region VI (concluded)				
100. Petrounited Terminal Services	Houston, TX	95°01'23"	29°33'51"	C/T
101. Phillips Petroleum	Borger, TX	101°22'05"	35°42'05"	SP
102. Phillips Petroleum	Pasadena, TX	95°10'53"	29°43'59"	C/T
103. Phillips Petroleum	Sweeny, TX	95°45'10"	29°04'24"	SP,C/T
104. Quintana-Howell	Corpus Christi, TX	97°27'30"	27°48'30"	SP
105. Shell Chemical	Houston, TX	95°01'45"	29°38'15"	C/T
106. Shell Oil	Deer Park, TX	95°07'33"	29°42'55"	LP
107. Shell Oil	Odessa, TX	102°19'20"	31°49'05"	SP
108. Standard Oil (Indiana)	Alvin, TX	95°11'55"	29°13'06"	C/T
109. Standard Oil (Indiana)/Amoco	Texas City, TX	94°55'45"	29°21'58"	LP,C/T
110. Sun Oil	Corpus Christi, TX	97°31'38"	27°49'57"	LP,C/T
111. Texaco	Port Arthur, TX	93°54'43"	29°52'00"	LP,C/T
112. Texaco/Jefferson Chemical	Port Neches, TX	93°56'00"	29°57'50	C/T
113. Union Carbide	Seadrift, TX	96°45'59"	28°30'38"	C/T
114. Union Carbide	Texas City, TX	94°56'33"	29°22'27"	C/T
115. USS Chemicals	Houston, TX	95°15'06"	29°42'18"	C/T
Region VII				
116. Chemplex	Clinton, IO	96°17'29"	41°48'24"	C/T
117. Getty Oil	El Dorado, KA	96°52'00"	37°47'10"	SP,C/T
118. Monsanto	St. Louis, MO	90°12'00"	38°35'00"	C/T
Region IX				
119. Atlantic Richfield	Wilmington, CA	118°14'30	33°48'49"	SP
120. Chevron	Richmond, CA	122°23'36"	37°56'12"	SP,C/T
121. Specialty Organics	Irwindale, CA	117°55'56"	34°06'18"	C/T

(continued)

Table B-1. Concluded

Plant	Location	Coordinates		Model Plant Type[a]
		Longitude	Latitude	
Region IX (continued)				
122. Standard Oil of California (Chevron Chemical)	El Segundo, CA	118°24'41"	33°54'39"	SP,C/T
123. Union Carbide	Torrance, CA	118°20'50"	33°51'11"	C/T
124. Witco Chemical	Carson, CA	118°14'13"	33°49'18"	C/T
125. Montrose Chemical	Henderson, NV	115°00'40"	36°02'28"	C/T
126. Stauffer Chemical	Henderson, NV	115°00'40"	36°02'28"	C/T

[a]C/T represents a benzene consumer or bulk storage terminal; LP represents a large producer of benzene; SP represents a small producer of benzene.

Table B-2. MODEL INPUTS FOR EACH TYPE OF MODEL PLANT

Type of model plant and tank number	Tank dimensions: Height (m)	Tank dimensions: Vertical cross-sectional area (m^2)	Baseline: Roof type[a]	Baseline: Emissions (kg/yr)
Benzene Producer: Large Facility (throughput of 224.6 x 10^6 liters/year)				
1	9	108	ncIFR	720
2	12	216	EFRps	2,190
3	5	40	cIFRps	480
4	9	81	cIFRps	590
5	13	169	ncIFR	680
6	9	216	ncIFR	1,360
7	15	405	ncIFR	1,820
Benzene Producer: Small Facility (throughput of 46.3 x 10^6 liters/yr)				
1	11	33	FR	1,270
2	13	169	ncIFR	680
3	11	88	ncIFR	500
4	7	224	cIFRps	2,170
Benzene Consumer or Bulk Storage Terminal				
1	11	132	ncIFR	640
2	15	270	cIFRps	970

[a]FR - Fixed-roof tank, IFR - internal floating-roof tank, ERF - external floating-roof tank, c - contact roof, nc - noncontact roof, ps - primary seal, ss - secondary seal, lm - liquid-mounted seal.

each tank for the baseline (current level) level of control. Emissions from all the tanks were assumed to be at ambient temperature, which the model assigns as 293°Kelvin. Because the gas exit velocity is negligible, it was assumed to be 0 m/s. The model was run in the rural mode. More information on the development of model plants and emission rates can be found in Chapter 2 of this document.

B.3 POPULATION AROUND PLANTS CONTAINING BENZENE STORAGE TANKS

The HEM was used to estimate the population that resides in the vicinity of each receptor coordinate surrounding each plant containing benzene storage tanks. A slightly modified version of the "Master Enumeration District List--Extended" (MED-X) data base is contained in the HEM and used for population pattern estimation. This data base is broken down into enumeration district/block group (ED/BG) values. MED-X contains the population centroid coordinates (latitude and longitude) and the 1970 population of each ED/BG in the United States (50 States plus the District of Columbia). For human exposure estimations, MED-X has been reduced from its complete form (including descriptive and summary data) to produce a randomly accessible computer file of the data necessary for the estimation. A separate file of county-level growth factors, based on 1978 estimates of the 1970 to 1980 growth factor at the county level, has been used to estimate 1980 population figures for each ED/BG. The population "at risk" to benzene exposure was considered to be persons residing within 20 km of plants containing benzene storage tanks. The population around each plant was identified by specifying the geographical coordinates of that plant. The geographical coordinates are shown for each plant in Table B-1.

B.4 POPULATION EXPOSURE METHODOLOGY

B.4.1 Exposure Methodology

The HEM uses benzene atmospheric concentration patterns (see Section B.2) together with population information (see Section B.3) to calculate population exposure. For each receptor coordinate, the concentration of benzene and the population estimated by the HEM to be exposed to that particular concentration are identified. The HEM multiplies these two numbers to produce population exposure estimates and sums these products for each plant. A two-level scheme has been adopted in order to pair concentrations and populations prior to the

computation of exposure. The two-level approach is used because the concentrations are defined on a radius-azimuth (polar) grid pattern with nonuniform spacing. At small radii, the grid cells are much smaller than ED/BG's; at large radii, the grid cells are generally much larger than ED/BG's. The area surrounding the source is divided into two regions, and each ED/BG is classified by the region in which its centroid lies. Population exposure is calculated differently for the ED/BG's located within each region.

For ED/BG centroids located between 0.1 km and 2.8 km from the emission source, populations are divided between neighboring concentration grid points. There are 96 (6 x 16) polar grid points within this range. Each grid point has a polar sector defined by two concentric arcs and two wind direction radials. Each of these grid points is assigned to the nearest ED/BG centroid identified from MED-X. The population associated with the ED/BG centroid is then divided among all concentration grid points assigned to it. The exact land area within each polar sector is considered in t.. apportionment.

For population centroids between 2.8 km and 20 km from the source, a concentrat'on grid cell, the area approximating a rectangular shape bounded by four receptors, is much larger than the area of a typical ED/BG (usually 1 km in diameter). Since there is a linear relationship between the logarithm of concentration and the logarithm of distance for receptors more than 2 km from the source, the entire population of the ED/BG is assumed to be exposed to the concentration that is geometrically interpolated radially and arithmetically interpolated azimuthally from the four receptors bounding the grid cell. Concentration estimates for 80 (5 x 16) grid cell receptors at 2.0, 5.0, 10.0, 15.0, and 20.0 km from the source along each of 16 wind directions are used as reference points for this interpolation.

In summary, two approaches are used to arrive at coincident concentration/population data points. For the 96 concentration points within 2.8 km of the source, the pairing occurs at the polar grid points using an apportionment of ED/BG population by land area. For the remaining portions of the grid, pairing occurs at the ED/BG centroids themselves, through the use of log-log and linear interpolation. (For a more detailed discussion of the methodology used to estimate exposures, see Reference 1.)

B.4.2 Total Exposure

Total exposure (persons-$\mu g/m^3$) is the sum of the products of concentration and population, computed as illustrated by the following equation:

$$\text{Total exposure} = \sum_{i=1}^{N} (P_i C_i) \qquad (1)$$

where

P_i = population associated with point i,
C_i = annual average benzene concentration at point i, and
N = total number of polar grid points between 0 and 2.8 km and ED/BG centroids between 2.8 and 20 km.

The computed total exposure is then used with the unit risk factor to estimate leukemia incidence. This methodology and the derivation of maximum lifetime risk are described in the following sections.

B.5 LEUKEMIA INCIDENCE AND MAXIMUM LIFETIME RISK

B 5.1 Unit Risk Factor

The unit risk factor (URF) for benzene is 9.9×10^{-8} (cases per year)/ ($\mu g/m^3$-person years), as calculated by EPA's Carcinogen Assessment Group (CAG). This factor is slightly lower than the factor derived by CAG at proposal.

Arguments have been advanced that the assumptions made by EPA (Carcinogen Assessment Group [CAG]) in the derivation of a unit leukemia risk factor for benzene represented "serious misinterpretation" of the underlying epidemiological evidence. Among the specific criticisms are: CAG (1) inappropriately included in its evaluation of the Infante et al. study two cases of leukemia from outside the cohort, inappropriately excluded a population of workers that had been exposed to benzene, and improperly assumed that exposure levels were comparable with prevailing occupational standards; (2) accepted, in the Aksoy et al. studies, an unreasonable undercount of the background leukemia incidence in rural Turkey, made a false adjustment of age, and underestimated the exposure duration; and (3) included the Ott et al. study in the analysis despite a lack of statistical significance.

EPA has reexamined and reevaluated each of the three studies. In summary, EPA concluded that one case of leukemia was inappropriately included from the Infante et al. study in computing the original unit risk factor. Additionally, EPA reaffirmed its decision to exclude dry-side workers from that study in developing the risk factor. The Agency agrees that the Aksoy et al. study was adjusted improperly for age; however, the exposures and durations of exposures are still considered reasonable estimates. The Ott et al. study was not eliminated from the risk assessment because the findings meet the test of statistical significance and because it provides the best documented exposure data available from the three epidemiological studies.

Based on these findings, the unit risk factor (the probability of an individual contracting leukemia after a lifetime of exposure to a benzene concentration of one part benzene per million parts air) was recalculated. The revised estimate resulted in a reduction of about 7 percent from the original estimate of the geometric mean, from a probability of leukemia of 0.024/ppm to a probability of leukemia of 0.022/ppm.

B.5.2 Annual Leukemia Incidence

Annual leukemia incidence (the number of leukemia cases per year) associated with a given plant is the product of the total exposure around that plant (in persons - $\mu g/m^3$) and the unit risk factor, 9.9×10^{-8}. Thus,

$$\text{Cases per year} = (\text{total exposure}) \times (\text{unit risk factor}), \qquad (2)$$

where total exposure is calculated according to Equation 1 and the unit risk factor equals 9.9×10^{-8}.

B.5.3 Maximum Lifetime Risk

The populations in areas surrounding plants containing benzene storage tanks have various risk levels of contracting leukemia from exposure to benzene emissions. Using the maximum annual average concentration of benzene to which any person is exposed, it is possible to calculate the maximum lifetime risk of leukemia (lifetime probability of leukemia to any person exposed to the highest concentration of benzene) attributable to benzene emissions using the following equation:

$$\text{Maximum lifetime risk} = C_{i,max} \times (\text{URF}) \times 70 \text{ years} \qquad (3)$$

where

$C_{i,max}$ = the maximum concentration among all plants at any receptor location where exposed persons reside,

URF = the unit risk factor, 9.9×10^{-8}, and

70 years = the average individual's life span.

B.5.4 Example Calculations

The following calculations illustrate how annual leukemia incidence and maximum lifetime risk were calculated for specific plants listed in Table B-1. Table B-3 presents the maximum annual average concentration and the total exposure for each plant under the baseline (current level) control level.

B.5.4.1 Annual Leukemia Incidence. As an example for calculating annual leukemia incidence the Gulf Oil plant in Philadelphia, Pennsylvania, is used. As shown in Table B-3, the total exposure under the current (baseline) level of emission control is 3.30×10^4 persons-$\mu g/m^3$. Therefore, under the baseline, the cases per year are computed according to Equation 2 as follows:

$$\text{Cases per year} = 3.30 \times 10^4 \times 9.9 \times 10^{-8}$$

$$\text{Cases per year} = 0.003$$

B.5.4.2 Maximum Lifetime Risk. Plant numbers 73 (Coastal States and Gas) and 117 (Sun Oil) had the highest maximum annual average benzene concentration of 5.22 $\mu g/m^3$. Using this maximum concentration and Equation 3, maximum lifetime risk under the current (baseline) level of control is calculated as follows:

$$\text{Maximum lifetime risk} = 5.22 \times 9.9 \times 10^{-8} \times 70$$

$$\text{Maximum lifetime risk} = 3.62 \times 10^{-5}$$

B.5.5 Summary of Impacts

Table B-4 summarizes the estimated nationwide impacts for the baseline (current level) level of emission control. The nationwide annual leukemia incidence was calculated by summing the total exposure over all the plants and multiplying by the unit risk factor. The maximum lifetime risk was calculated as shonw in Section B.5.4.2.

Table B-3. ESTIMATED MAXIMUM CONCENTRATION AND EXPOSURE FOR BENZENE STORAGE TANKS

Plant number	Baseline: Maximum annual average benzene concentration[a] ($\mu g/m^3$)	Baseline: Total exposure (person $\mu g/m^3$)
Region II		
1	4.45×10^{-1}	5.26×10^{3}
2	2.50×10^{-1}	2.27×10^{3}
3	2.60×10^{0}	3.05×10^{4}
4	1.00×10^{-1}	1.44×10^{4}
5	3.03×10^{0}	2.32×10^{4}
6	3.19×10^{0}	3.95×10^{3}
7	7.44×10^{-1}	7.93×10^{2}
8	b	b
9	b	b
10	b	b
11	b	b
12	b	b
Region III		
13	1.77×10^{0}	1.21×10^{3}
14	2.50×10^{-1}	3.20×10^{2}
15	8.67×10^{-3}	8.50×10^{1}
16	2.50×10^{-1}	1.31×10^{2}
17	2.50×10^{-1}	5.20×10^{2}
18	4.50×10^{-1}	3.75×10^{3}
19	3.03×10^{0}	3.30×10^{4}
20	1.77×10^{0}	1.21×10^{3}
21	1.77×10^{0}	4.50×10^{3}
22	4.50×10^{-1}	2.32×10^{3}
23	1.80×10^{-2}	5.39×10^{2}
24	2.50×10^{-1}	1.21×10^{2}
25	9.62×10^{-3}	7.24×10^{1}
26	5.00×10^{-1}	1.03×10^{2}
27	4.87×10^{-1}	1.07×10^{3}

(continued)

Table B-3. Continued

Plant number	Baseline: Maximum annual average benzene concentration[a] ($\mu g/m^3$)	Baseline: Total exposure (person $\mu g/m^3$)
Region IV		
28	3.47×10^{-1}	1.70×10^{3}
29	1.00×10^{-1}	4.04×10^{2}
30	1.00×10^{0}	2.57×10^{3}
31	1.04×10^{-2}	6.45×10^{1}
32	1.92×10^{-2}	1.19×10^{2}
33	1.53×10^{-2}	1.41×10^{2}
34	9.78×10^{-3}	3.69×10^{2}
35	8.01×10^{-1}	3.77×10^{2}
Region V		
36	3.70×10^{-1}	5.30×10^{3}
37	2.50×10^{-1}	1.96×10^{2}
38	4.11×10^{-1}	2.67×10^{3}
39	6.05×10^{-3}	4.75×10^{1}
40	3.70×10^{-1}	4.91×10^{2}
41	2.51×10^{0}	3.42×10^{3}
42	1.64×10^{0}	3.43×10^{3}
43	1.00×10^{0}	2.51×10^{2}
44	3.88×10^{-1}	4.81×10^{2}
45	2.87×10^{0}	1.22×10^{4}
Region VI		
46	1.00×10^{-1}	1.63×10^{2}
47	2.50×10^{-1}	1.42×10^{2}
48	2.50×10^{-1}	6.57×10^{2}
49	5.00×10^{-1}	8.88×10^{2}
50	2.50×10^{-1}	3.65×10^{2}
51	2.50×10^{-1}	$1.59. \times 10^{2}$
52	2.66×10^{0}	1.49×10^{3}

(continued)

Table B-3. Continued

Plant number	Baseline: Maximum annual average benzene concentration[a] ($\mu g/m^3$)	Baseline: Total exposure (person $\mu g/m^3$)
Region VI (continued)		
53	1.00×10^{0}	1.05×10^{4}
54	5.75×10^{-1}	3.51×10^{2}
55	2.61×10^{-2}	2.44×10^{2}
56	2.50×10^{-1}	2.01×10^{2}
57	3.72×10^{0}	1.55×10^{4}
58	2.50×10^{-1}	1.35×10^{2}
59	5.00×10^{-1}	2.29×10^{2}
60	1.00×10^{0}	1.08×10^{4}
61	2.50×10^{0}	1.14×10^{3}
62	3.19×10^{0}	5.29×10^{3}
63	4.39×10^{-1}	4.61×10^{3}
64	8.13×10^{-1}	7.39×10^{2}
65	1.00×10^{0}	1.60×10^{3}
66	2.50×10^{0}	7.50×10^{2}
67	1.00×10^{0}	2.03×10^{3}
68	5.19×10^{0}	4.34×10^{3}
69	1.00×10^{0}	1.95×10^{4}
70	2.50×10^{-1}	3.43×10^{2}
71	3.25×10^{-1}	4.55×10^{2}
72	2.01×10^{0}	1.54×10^{4}
73	5.22×10^{0}	4.89×10^{3}
74	3.78×10^{0}	1.24×10^{3}
75	1.00×10^{-1}	3.59×10^{2}
76	5.00×10^{-1}	7.30×10^{3}
77	3.10×10^{0}	1.08×10^{3}
78	1.00×10^{0}	1.21×10^{3}
79	1.00×10^{-1}	3.42×10^{2}

(continued)

Table B-3. Continued

Plant number	Baseline: Maximum annual average benzene concentration[a] ($\mu g/m^3$)	Baseline: Total exposure (person $\mu g/m^3$)
Region VI (continued)		
80	2.50×10^{-1}	3.57×10^{2}
81	1.00×10^{-1}	3.42×10^{2}
82	1.00×10^{-1}	3.40×10^{2}
83	1.00×10^{-1}	5.94×10^{2}
84	4.12×10^{-1}	7.13×10^{2}
85	1.00×10^{0}	4.70×10^{3}
86	4.39×10^{-1}	3.62×10^{3}
87	8.13×10^{-1}	7.71×10^{2}
88	2.50×10^{-1}	8.00×10^{2}
89	2.50×10^{-1}	2.07×10^{2}
90	1.00×10^{0}	1.95×10^{3}
91	2.50×10^{-1}	1.32×10^{2}
92	4.72×10^{0}	1.36×10^{4}
93	1.56×10^{-2}	8.62×10^{1}
94	3.07×10^{0}	5.13×10^{3}
95	2.26×10^{0}	2.16×10^{3}
96	2.50×10^{0}	3.24×10^{3}
97	1.00×10^{0}	1.71×10^{2}
98	3.10×10^{0}	3.81×10^{3}
99	5.00×10^{-1}	6.24×10^{2}
100	8.13×10^{-1}	7.33×10^{2}
101	1.00×10^{0}	2.72×10^{2}
102	8.13×10^{-1}	2.60×10^{3}
103	1.00×10^{0}	2.79×10^{2}
104	3.07×10^{0}	1.73×10^{3}
105	8.13×10^{-1}	8.31×10^{2}
106	2.50×10^{0}	7.55×10^{3}

(continued)

Table B-3. Concluded

Plant number	Baseline: Maximum annual average benzene concentration[a] ($\mu g/m^3$)	Baseline: Total exposure (person $\mu g/m^3$)
Region VI (concluded)		
107	1.85×10^{0}	1.76×10^{3}
108	3.36×10^{-3}	9.02×10^{0}
109	3.10×10^{0}	2.66×10^{3}
110	5.22×10^{0}	2.13×10^{3}
111	2.50×10^{0}	3.60×10^{3}
112	1.00×10^{-1}	6.22×10^{2}
113	5.00×10^{-1}	2.47×10^{1}
114	2.50×10^{-1}	4.88×10^{2}
115	4.39×10^{-1}	4.55×10^{3}
Region VII		
116	6.11×10^{-3}	1.58×10^{1}
117	5.00×10^{-1}	6.08×10^{2}
118	2.50×10^{-1}	2.82×10^{3}
Region IX		
119	2.85×10^{0}	2.44×10^{4}
120	4.50×10^{0}	1.07×10^{4}
121	5.61×10^{-1}	6.29×10^{3}
122	3.85×10^{0}	2.40×10^{4}
123	7.33×10^{-1}	6.93×10^{3}
124	5.61×10^{-1}	8.47×10^{3}
125	2.50×10^{-1}	5.18×10^{2}
126	2.50×10^{-1}	5.18×10^{2}

[a]This table lists the maximum annual average benzene concentration to which at least one person is exposed.

[b]Population estimate is not included in the HEM for this plant.

Table B-4. ESTIMATED NATIONWIDE HEALTH IMPACTS FOR BENZENE STORAGE TANKS

	Baseline
Max. Annual Average Concentration ($\mu g/m^3$)	5.22
Maximum Lifetime Risk	3.6×10^{-5}
Total Exposure (persons-$\mu g/m^3$)	4.37×10^{5}
Incidence (cases/yr)	0.043

B.6 UNCERTAINTIES

Estimates of both leukemia incidence and maximum lifetime risk are primarily functions of estimated benzene concentrations, populations, the unit risk factor, and the exposure model. The calculations of these variables are subject to a number of uncertainties of various degrees. Some of the major uncertainties are identified below.

B.6.1 Benzene Concentrations

Modeled ambient benzene concentrations depend upon: (1) plant configuration, which is difficult to determine for more than a few plants; (2) emission point characteristics, which can be different from plant to plant and are difficult to obtain for more than a few plants; (3) emission rates, which may vary over time and from plant to plant; and (4) meteorology, which is seldom available for a specific plant. The particular dispersion modeling used can also influence the numbers. The dispersion models also assume that the terrain in the vicinity of the source is flat. For sources located in complex terrain, the maximum annual concentration could be underestimated by several fold due to this assumption. The dispersion coefficients used in modeling are based on empirical measurements made within 10 kilometers of sources. These coefficients become less applicable at long distances from the source, and the modeling results become more uncertain. Assuming the inputs to the dispersion model are accurate, the predicted benzene concentrations are considered to be accurate to within a factor of 2. This uncertainty factor was not included in the calculations in this analysis.

The Industrial Source Complex - Long Term (ISC-LT) dispersion model is considered to be a more complex and accurate dispersion model than the dispersion model subprogram of the HEM. However, it is too resource-intensive for modeling a large number of sources, such as benzene storage vessels. To evaluate the effect of using the HEM dispersion model, the ISC-LT was run on the model plants for several geographic sites and the results were compared with those from the HEM dispersion model. The results of the analysis can be found in Docket A-80-14, Item IV-B-4.

For three sites (New Orleans, Houston, and Chicago) the maximum and mean ring concentrations predicted by each model were compared. In all cases, the ISC-LT resulted in higher estimates than the dispersion model

of the HEM. For the same three sites and two additional sites (Los Angeles and Philadelphia), the concentration at each receptor point times the corresponding area around the receptor point was summed over all receptors at each plant. (NOTE: Docket Item IV-B-4 calls this sum "total exposure." The usage in the docket item is different from that defined in Section B.4 of this appendix.) The ISC-LT results in a higher estimate of this sum (ranging from about 20 to 60 percent) than the HEM dispersion model for New Orleans, Houston, and Philadelphia. For Chicago and Los Angeles, the HEM and ISC-LT give very similar results for this sum, within 10 percent of one another.

This analysis shows that the ISC-LT and the HEM dispersion model may give different results. In many cases, the ISC-LT predicts higher concentrations than the HEM. However, because of the degree of uncertainty in the basic data available for the model and in dispersion analysis, the degree of effort to model all the plants specifically using the more sophisticated dispersion model (ISC-LT) is not warranted.

B.6.2 Exposed Populations

Several simplifying assumptions were made with respect to the assumed exposed population. The location of the exposed population depends on the accuracy of the census data in the HEM. In addition, the exposed population was assumed to be immobile, remaining at the same location 24 hours per day, 365 days per year, for a lifetime (70 years). This assumption may be counterbalanced to some extent (at least in the calculation of incidence) by the assumption that no one moves into the exposure area either permanently as a resident or temporarily as a transient. The population "at risk" was assumed to reside within 20 km of each plant regardless of the estimated concentration at that point. The selection of 20 km is considered to be a practical modeling stop-point considering the uncertainty of dispersion estimates beyond 10 km. The results of dispersion modeling are felt to be reasonably accurate within that distance (see above). The uncertainty of these assumptions has not been quantified.

B.6.3 Unit Risk Factor

The unit risk factor contains uncertainties associated with the occupational studies of Infante, Aksoy, and Ott, and the variations in the dose/response relationships among the studies. Other uncertainties regarding the occupational studies and the workers exposed that may affect the unit risk factor were raised during the public comment period and focus on assumptions and inconclusive data contained in the studies. However, those uncertainties have not been quantified.

B.6.4 Other Uncertainties

There are several uncertainties associated with estimating health impacts. Maximum lifetime risk and annual leukemia incidence were calculated using the unit risk factor, which is based on a no-threshold linear extrapolation of leukemia risk and applies to a presumably healthy white male cohort of workers exposed to benzene concentrations in the parts per million range. It is uncertain whether the unit risk factor can be accurately applied to the general population, which includes men, women, children, nonwhites, the aged, and the unhealthy, who are exposed to concentrations in the parts per billion range. It is uncertain whether these widely diverse segments of the population may have susceptabilities to leukemia that differ from those of workers in the studies. Furthermore, while leukemia is the only benzene health effect considered in these calculations, it is not the only possible health effect. Other health effects, such as aplastic anemia and chromosomal aberrations, are not as easily quantifiable and are not reflected in the risk estimates. Although these other health effects have been observed at occupational levels, it is not clear if they can result from ambient benzene exposure levels. Additionally, benefits that would affect the general population as the result of indirect control of other organic emissions in the process of controlling benzene emissions from benzene storage tanks are not quantified. Possible benzene exposures from other sources also are not included in the estimate. For example, an individual living near a benzene storage tank is also exposed to benzene emissions from automobiles. Finally, these estimates do not include possible cumulative or synergistic effects of concurrent exposure to benzene and other substances.

B.8 REFERENCES

1. Systems Applications, Inc. Human Exposure to Atmospheric Concentrations of Selected Chemicals. (Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina). Volume I, Publication Number EPA-2/250-1, and Volume II, Publication Number EPA-2/250-2. May 1980.

2. Busse, A.D. and J.R. Zimmerman. User's Guide for the Climatological Dispersion Model. (Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.) Publication Number EPA-R4-73-024. December 1973.

3. Albert, R. E. Carcinogen Assessment Group's Final Report on Population Risk to Ambient Benzene Exposures. U.S. Environmental Protection Agency. Publication No. EPA-450/5-80-004. Docket Number A-79-27-II-A-28. January 1979.